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NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO MEETING PROCEEDINGS 54

The Capability of Virtual Reality to Meet Military Requirements

(la Capacité de la réalité virtuelle à répondre aux besoins militaires)

Papers presented at the RTO Human Factors and Medicine Panel (HFM) Workshop held in Orlando, Florida, USA, 5-9 December 1997.

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Abstract
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Subject Terms
Human factors engineering; Simulation; Military operations; Helmet mounted displays; Requirements; Motion sickness; Logistics; Man computer interface; Resources; Virtual reality; Military training; Virtual environments; Robotics Locomotion

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14. Abstract

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The Research and Technology Organization (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote cooperative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective coordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also coordinates RTO's cooperation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of initial cooperation.

The total spectrum of R&T activities is covered by 7 Panels, dealing with:

- SAS Studies, Analysis and Simulation
- SCI Systems Concepts and Integration
- SET Sensors and Electronics Technology
- IST Information Systems Technology
- AVT Applied Vehicle Technology
- HFM Human Factors and Medicine
- MSG Modelling and Simulation

These Panels are made up of national representatives as well as generally recognised 'world class' scientists. The Panels also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier cooperation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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The Capability of Virtual Reality to Meet Military Requirements

(RTO MP-54)

Executive Summary

PURPOSE

The purpose of the workshop was to examine military requirements for Virtual Reality technology, consider human factors issues in the use of Virtual Reality and review recent research in development of Virtual Reality applications to meet military needs.

SUMMARY

The workshop was organized into three daylong sessions. The first day focused on military applications for Virtual Reality systems and identified particular requirements for Human Factors research to meet the requirements. The second day examined Human Factors issues in the use of Virtual Reality technology. Presentations discussed sensory interfaces, measures of effectiveness, importance of the sensation of presence, and cybersickness. The third day reviewed assessment methods and applications research. Speakers reviewed existing or completed Virtual Reality projects designed to meet military needs. The papers discussed how the projects overcame human factors problems and how their effectiveness was evaluated. Summaries of the paper presentations are incorporated in the chairman's notes for each day of the workshop.

MAIN CONCLUSIONS

Virtual Reality technology is of great interest to the military. Requirements for its use encompass a wide range of applications including concept development of systems for dismounted combatants, mission rehearsal for special operations, training ship handling skills, telerobotics, and practicing military medical procedures. Virtual Reality's success in meeting these needs will be determined by the ability of its human-computer interfaces to provide the means necessary to deliver stimuli and allow appropriate responses from those using it. These human factors issues were the focus of the workshop. Through research on Virtual Reality's interface technologies and applications, it is clear that Virtual Reality has promise for the military, but serious human-computer problems limit its potential. In particular, helmet mounted displays need to be improved, cybersickness limits use by a significant number of people, haptics and walking interfaces are in their infancy. The workshop pointed to these and other areas that require further research and development in order for Virtual Reality to meet its potential for the military.

MAJOR RECOMMENDATIONS

Research needs to continue on the many human factors issues involved in the use of Virtual Reality to meet military requirements. The Virtual Reality technologies are maturing and the feasibility of developing cost-effective Virtual Reality based tools is increasing. Research on the usability of this technology will enable militaries to be smart buyers. It will ensure that Virtual Reality hardware and software is capable of meeting the perceptual, fidelity, transfer of training, and health and safety requirements of applications. Military research needs to focus on those issues that are unique to the military and not likely to be addressed by other potential users of Virtual Reality.

la Capacité de la réalité virtuelle à répondre aux besoins militaires

(RTO MP-54)

Synthèse

OBJET

Cet atelier a eu pour objet : d'examiner les besoins militaires en matière de technologies de réalité virtuelle, de considérer les aspects facteurs humains de la réalité virtuelle et de faire une synthèse des travaux de recherche récents sur le développement d'applications de réalité virtuelle pour satisfaire aux besoins militaires.

RÉSUMÉ

L'atelier a été organisé en trois sessions d'une journée : La première journée a porté sur les applications militaires des systèmes à base de réalité virtuelle et a identifié des voies de recherche dans le domaine des facteurs humains susceptibles de répondre aux besoins. La deuxième journée a été dédiée au problème des facteurs humains dans l'application des technologies de réalité virtuelle. Les communications présentées ont traité des interfaces sensorielles, de l'évaluation de l'efficacité, de l'importance de la sensation de présence et des maladies cybernétiques. La troisième journée a privilégié les méthodes d'évaluation et la recherche en applications. Les conférenciers ont examiné les projets existants ou réalisés dans le domaine de la réalité virtuelle appliquée aux besoins militaires. Les présentations ont décrit l'approche des problèmes liés aux facteurs humains et leur résolution, ainsi que les méthodes retenues pour l'évaluation de l'efficacité des différents projets. Des résumés des présentations ont été incorporés aux notes du Président pour chaque journée de l'atelier.

CONCLUSIONS PRINCIPALES

Les technologies de réalité virtuelle sont d'un grand intérêt pour les militaires. La demande pour ces technologies couvre un large éventail d'applications comprenant le développement de concepts de systèmes pour infanterie débarquée, la préparation de missions pour les opérations spéciales, l'entraînement au pilotage des navires, la télérobotique et la formation à l'usage des procédures médicales militaires. La capacité de la réalité virtuelle à répondre à ces besoins sera déterminée par la capacité de ses interfaces homme-machine à transmettre les stimuli et à solliciter les réponses appropriées de la part des utilisateurs. L'atelier a fait une place privilégiée à ces sujets. Les résultats des recherches entreprises sur les technologies d'interface de la réalité virtuelle indiquent très clairement que si la réalité virtuelle est prometteuse pour les applications militaires, son potentiel se trouve limité par d'importants problèmes homme-machine. En particulier, les visuels montés sur casque sont à améliorer, les malaises cybernétiques limitent l'accès à ces technologies pour bon nombre de personnes et les interfaces haptiques et ambulatoires sont à leur début. L'atelier a mis en exergue ces domaines entre autres, pour lesquels des travaux de recherche et développement complémentaires sont nécessaires pour que la réalité virtuelle puisse atteindre la plénitude de ses possibilités militaires.

RECOMMANDATIONS PRINCIPALES

Il importe de poursuivre les recherches sur l'influence des facteurs humains dans l'application des technologies de réalité virtuelle aux besoins militaires. Ces technologies viennent à maturité et le développement d'outils basés sur la réalité virtuelle à coût abordable semble de plus en plus accessible. Des recherches doivent être entreprises sur la facilité d'utilisation de ces technologies afin de permettre aux militaires de s'en approvisionner en connaissance de cause. Ils pourraient ainsi s'assurer que le matériel et les logiciels de réalité virtuelle sont compatibles avec les exigences en matière de perception, de fidélité, de transfert d'entraînement et d'hygiène et sécurité des applications. Les chercheurs militaires doivent se concentrer sur les questions qui concernent uniquement les applications militaires et qui ne sont pas examinés par d'autres utilisateurs de la réalité virtuelle.

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SESSION DAY 3: ASSESSMENT AND EXPERIMENTAL APPLICATIONS OF VIRTUAL REALITY TECHNOLOGY

Foreword

Virtual Reality (VR) has the potential to meet needs across a wide range of applications within the military. VR military applications include combat training, mission rehearsal, concept development, materiel design, materiel testing, medical training, and personnel selection. The ability of VR in meeting requirements in these areas will depend upon establishing an effective match between technological capabilities, application requirements and human sensory, cognitive and motor capabilities and limits.

NATO Research Study Group 28 (RSG 28) was established to: 1) identify human factors issues involved in the use of VR technology for military purposes; 2) determine the state of knowledge with regard to those issues; and 3) recommend a research agenda that will address critical questions and enable effective products to be produced to meet the military's needs. RSG 28 has adopted the following definition for its use of the term Virtual Reality:

Virtual Reality is the experience of being in a synthetic environment and the perceiving and interacting through sensors and effectors, actively and passively, with it and the objects in it, as if they were real. Virtual Reality technology allows the user to perceive and experience sensory contact and interact dynamically with such contact in any or all modalities.

This report summarizes a workshop conducted by RSG28. The purpose of the workshop was to: 1) discuss issues related to military requirements for Virtual Reality; 2) consider human factors issues and research focusing on the interfaces between human beings and virtual environments; and 3) review VR military applications research and assessment methods. A day of the three-day workshop focused on each of these broad topics. The workshop brought together experts in Virtual Reality from ten NATO countries. It was attended by over 60 people and included 30 paper presentations. Stephen Goldberg, US served as the overall workshop chair. Neil Hardinge, UK chaired the first day on military requirements. Robert Breaux, US chaired the second day on human factors issues, and Peter Werkhoven, The Netherlands, chaired the final day, focused on applications research.

The workshop demonstrated that the military is looking to VR technology to answer a number of its problems from dismounted infantry simulations to training ship-handling skills. The technology is improving, and there have been VR research success stories. Nevertheless, substantial improvements in VR technology are required before a natural man-machine interface is available for many applications, and products are regularly produced that will be institutionalized for use by the military.

Welcome

Médecin Chef des Services Papin welcomed the participants to the open workshop and outlined the aims of the Research Study Group. He provided two definitions of virtual reality (VR) for the workshop to consider. The working definition of the RSG is, “Virtual Reality Technology is a multi-dimensional human experience which is totally or partially computer generated and can be accepted by those experiencing the environment as consistent.”

General Papin also gave his own definition of VR. In his lectures, he defines VR as having 5 key features (the 5 I s), as follows:

– Information (computer-generated)
– Interface (using a physical interface)
– Illusion (of the real-world)
– Immersive (in a virtual environment)
– Imagination (imaginative rendering of the real-world by computer-programmers).

It is expected that VR systems will be used by the military for:

– Design (to develop man-machine systems suitable for military tasks)
– Training (to teach new skills & knowledge in complex environments)
– Rehearsal (to practice skills and procedures in operational settings)
– Telepresence (i.e. remote interaction with a real object as with robotic sensors)
– Test & evaluation (e.g. of new equipment or in new environments)
– Operational analysis (using man in the loop to assess outcomes of military forces, tactics, etc).

The aim of this group is to study the human factors problems arising from these kinds of applications. Each day of the workshop is devoted to examining one of the group’s 3 principal themes — military applications; human factors issues; virtual reality technologies.

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MILITARY REQUIREMENTS FOR VIRTUAL REALITY TECHNOLOGY

Day Chairman: Neil Hardinge

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DAY 1: MILITARY APPLICATIONS

1. Neil Hardinge highlighted the objective of the first day of the workshop - to examine the military applications for virtual reality systems and to identify the particular requirements for Human Factors research and related system design that these generate. In particular he invited the workshop to consider several key questions:

What Does The Military Want From VR Technologies?

- What is special about the context in which that need must be met?
- Who are the potential users of VR systems?
- What do you see as a likely solution to the requirement?
- How will you know if you have met the need?

He invited the speakers, who represented a broad range of military users - some of them military personnel who defined the operational requirement for military systems, some of them civilians associated with the development of VR systems - to describe their requirements and to identify the particular problems that they would like this group to address.

2. The first speakers, Cdr Kvisgaard and Lt Cdr Thomasson from the Royal Norwegian Navy (RNoN), described the approach to training design that is being adopted by the Norwegian Naval Training Academy. They described the philosophy of training design, the new organisational structure of the Academy and how these would determine the RNoN's approach to the design of training systems - especially those that involved simulation and virtual reality. They emphasised the importance of specification, cost-effectiveness and evaluation in the Norwegian approach and related this to the current acquisition of a navigation and shiphandling simulator using 2D displays. The RNoN's new approach to training needs analysis aims to incorporate the training needs and educational processes more effectively in the technical specification. They suggested that the capacity to develop consistent virtual environment databases which capture the environment, objects and effects will be the most significant development and could see this providing the basis for a new command control and information system.

3. Dr. Terry Allard from the US Office of Naval Research (ONR) outlined the requirements of the US Navy and Marine Corps for immersive VR systems for training and operations. Their compactness and inherent reconfigurability could make immersive VR systems an ideal medium for field and shipboard deployable training systems. He described the prototype for training shiphandling skills (VESUB) that ONR has funded and which is now being assessed in the USN warfare officers school. The Marine Corps identified training for urban warfare as their highest priority and Dr. Allard described how the small unit tactical trainer (SUTT) has been developed to help train distributed teams and teams on combat deployment in skills such as marksmanship, house to house search, situational awareness, etc. For military operations, he indicated how VR systems are used to view the displays and to manipulate remotely operated vehicles (ROVs) such as undersea ROVs for mine countermeasures or submarine rescue work. He also described current work to explore their value as a display medium for members of ship combat information centres.

4. As part of the Directorate of Operational Requirements for Training and Light Weapons Systems (Land), Lieutenant Colonel Nigel Gallier is directly involved in specifying the requirements for new military systems for the UK Army. Mike Kelly - one of the assignment managers whose research programme is driven by those requirements - delivered the presentation. The UK's Army Training Strategy has identified a range of training systems in which simulation and VR technologies play an essential role. He identified the range of weapons systems for which VR has been selected as the appropriate training medium. This creates several challenges: to ensure that the most cost-effective technical solutions are developed; to ensure that new training curricula and training approaches are developed which will capitalise on the

Paper presented at the RTO HFM Workshop on "The Capability of Virtual Reality to Meet Military Requirements", held in Orlando, USA, 5-9 December 1997, and published in RTO MP-54.

training potential of these new media; and to develop supporting training features - such as after action review facilities. Of particular importance is the development of methods of performance measurement and training effectiveness measurement that can ensure that these systems make the essential contribution to operational effectiveness that has been assigned to them.

5. Mike Kelly then described a research programme of his own that addresses the unique problems created by using virtual reality to train micro-aperture surgery (MAS, or keyhole surgery). VR is a natural training medium for this kind of work. It is normally mediated by television images and touch, and doctors have usually had little or no training equipment. Mr. Kelly's work has provided a task analysis - with surprising results - and has developed some new training devices. It has examined the relative contribution of force feedback features and has exploited the availability of organ models on the World Wide Web. Perhaps more importantly, the task and the VR system that he is developing lend themselves to remote operations in, for example, field hospitals. Originally supported by civilian medical groups, this programme is now also being sponsored by the UK Army.

6. Jan Chervanek described US efforts to integrate the different aspects of (constructive, virtual and live) simulation for dismounted soldiers to provide joint training and warfighting solutions. The testbed at Fort Benning provides a synthetic environment of urban terrain and links a number of different individual combatants and computer generated forces. He described the enhancements that are planned and the technical challenges to be overcome. Although the programme has a strong technical focus, it also generates Human Factors issues - such as how to refine the manned virtual interfaces so that they realistically represent visual, sound and motion cues and how to model and validate the behaviour of individual combatants.

7. H. A. Warren of DERA, spoke about teleoperation of unmanned ground vehicles (UGVs) for operations such as reconnaissance and mine clearance. He outlined the advantages and disdvantages of using UGVs for military tasks. UGVs reduce the risk to the human operator, thereby allowing for bolder concepts of operation. In addition, the UGV itself is not prone to fatigue, boredom, or stress, all of which can adversely affect mission success. They also aid in the goal of manpower reduction. However, they are also expensive, lack user confidence and acceptance, are an increased logistical burdern, and are less adaptable and flexible than human operators. Mr. Warren then presented an overview of the engineering changes made to the AVRE for remote operation.

8. Mr. P. Gibson of DERA outlined telepresence and issues in using remotely operated vehicles. He noted that fully immersive VR might not be needed as simple cues can produce a mental framework that allows the user to predict future events. After presenting a background on what type of sensory data is needed for complete telepresence, he again argued that such complexity is not needed, as the user's imagination will fill in any missing information. This more minimalist perspective is particularly relevant given the expense and difficulty in implementing some types of teleoperational systems. Therefore, research should also focus on what cues are necessary to aid the imagination. He then applied these ideas to a remote control tank system.

9. LTC Stone described the usefulness of the Virtual Reality Markup Language (VRML) for the Functional Description of the Battlespace (FDB), which is the Army domain modeled for simulation development, to teach concepts needed in complex domain modeling. The FDB data is comprised of four main categories: 1) Human Characteristics, for example, behaviors and capabilities; 2) Systems and Materiel, including the impact of supply and maintenance operations; 3) Physical Environment, including natural and manmade conditions and their dynamic changes; and 4) Organizations, covering cognitive processes of command and control

10. Tom Mastaglio provided a completely different perspective to the day's proceedings by discussing the factors that make VR technology and HF research important for commercial applications. For example, he now works for a private agency that seeks to transfer military technology to commercial applications.

Using VR for system prototyping was not discussed that day but it was the subject of a presentation on Day 3. There were no presentations on Air systems requirements on the first day. There is a vigorous work programme in this area - especially in the development of helmet mounted displays, augmented reality presentations and control interfaces to reduce pilot workload. The proceedings of the 1996 meeting of the previous AGARD Panel (1) provide a good insight into that work, and (2) it is hoped that increased interchange in the future will advance the work of the interest groups. Members of the aerospace community were represented in the audience and were well represented in the first RSG28 workshop.

DISCUSSION

The chairman put a number of questions before the speakers and audience to determine their views:

- What special advantages might VR provide?
- What are the costs?
- What are the benefits?
- What barriers - human factors, operational issues, technological limitations, etc - will users need to overcome?
- How can the R&D community help facilitate the development of effective VR systems?

INVESTMENT EVALUATION OF TECHNOLOGY-BASED TRAINING SYSTEMS: TRAINING NEEDS ANALYSIS IN THE ROYAL NORWEGIAN NAVY

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ABSTRACT

This paper describes the results of a research done in the Royal Norwegian Navy into the decision structure of the evaluation process of investing in technology-based training systems. A comprehensive methodology was developed, that evaluates technology-based training systems as information systems. The evaluation method can reveal cost driving training objectives and make sure focus on the strategic value of the information system components is maintained.

INTRODUCTION

The Royal Norwegian Navy (RNoN) is currently evaluating investments in new operational equipment. Investments in technology-based training systems are a part of these investments. The RNoN has developed a cost/benefit analysis method that is particularly suited to evaluate technology-based training systems. The investment evaluations conducted so far have merely focused on the training needs.

A more comprehensive methodology has now been developed, that evaluates technology-based training systems as information systems, and also takes account of their technological and life-cycle consequences. The evaluation method was developed by extensive literature investigation and case studies. The outcome of the case studies was used to improve the decision structure of the evaluation method. This method was developed in a research co-operation between Delft University of Technology in The Netherlands and the Naval Training Establishment HNoMS Tordenskjold in Norway.

TECHNOLOGY-BASED TRAINING SYSTEMS

This term can best be defined by other definitions. An *information system* can be defined as a collection of software, hardware, people, procedures, and data (Brussaard, 1994). Further, an *instructional system* can be defined as an arrangement of resources and procedures used to promote training (Gagné, Briggs, & Wagner, 1992). In this research the context of information systems was within the instructional system where information systems are used to promote training. *Training* is the learning or acquisition of skills, knowledge and attitudes in order to enhance performance at a given task (Burniston & Tayler, 1995).

In this paper the term *technology-based training* implies the use of information systems in any part of the instructional system. To emphasise that an information system is used to promote training, the term chosen is *technology-based training system*. This implies that technology-based training systems must also consist of the five information system components.

Paper presented at the RTO HFM Workshop on "The Capability of Virtual Reality to Meet Military Requirements", held in Orlando, USA, 5-9 December 1997, and published in RTO MP-54.

Case 1: Communication Trainer

The communication trainer was used in the training of internal and external operational communication procedures. The communication trainer is an integrated part of the existing technology-based training systems at the Naval Training Establishment HNoMS Tordenskjold. The main objectives of the communication trainer are: to take care of all types of training, covering procedures and plans for using existing operational communication equipment. Secondly, internal communication between trainees and trainees/instructor. The third objective was to provide a standard platform for voice communication for existing and future technology-based training systems within the RNoN.

Case 2: Scenario Management System

The scenario management system aims to improve the instructor's working environment by providing the instructor with the required tools for supporting the training process. The system's main objectives were to enable re-design of the instructor function to reduce the number of instructors involved in the training process. Further, it was intended to develop a standard instructor workstation and a prototype of an interconnection device for the Navy's future technology-based training systems.

THE EVALUATION METHOD

The idea behind the *evaluation method*[1] described in this paper is to provide a structured approach to the decision process of investing in technology-based training systems. An analysis of *training needs*, information system *components* and *costs* are required before a decision can be made on what investment strategy to pursue. These analyses are important to prevent overlooking unfavourable consequences in the initial enthusiastic planning phase.

In the context of evaluation of technology-based training systems the term *value* is defined as the sum of associated costs, benefits and risks of the desired competence level and its support technology. In other words, value can be structured into the three components of (1) training domain evaluation, (2) technology domain evaluation and (3) cost evaluation. These evaluations can be done by means of the method outlined in Figure 1. Consequently, to determine the value of different investment strategies requires a structured approach by the RNoN organisation. The different elements of the method (Figure 1) are described in the following sections.

Identify System & Search Space

When a particular problem is perceived, it is of course important to be sure that an associated training need exists. It may be that an apparent need can be satisfied more economically in some other way, for example by a change in the organisation or the introduction of a different personnel policy (Akerjordet, 1993; Patrick, 1992).

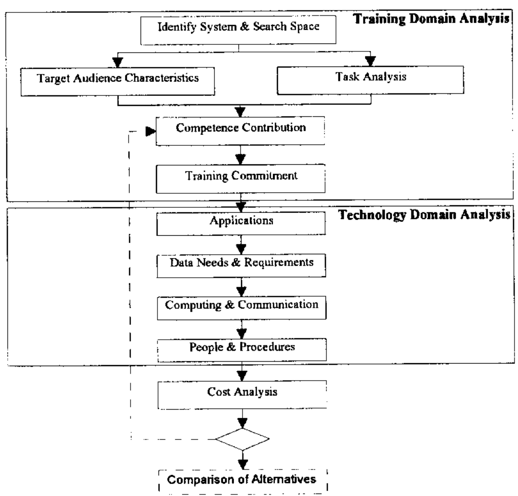

Figure 1. Method for investment evaluation of technology-based training systems (Svendsen, 1996)

[1] The term often used for the evaluation process of technology-based training systems is: *training needs analysis* (TNA) (HMSO 247, 1992; RNoN NSST, 1995; Gramson, 1995).

Identification of needs, problems, and opportunities are done in order to trace valuable technology-based training system solutions for the organisation (van Reeken, 1994). The identification-process can be carried out on the basis of the information system strategy formulation principle described by Earl (1989). It can be done in three complementary ways: top-down, bottom-up, and inside-out. This process can also be used to evaluate technology-based training system investment strategies. The way this identification process is performed is by means of an approach strategy. The three main *approach strategies* are; (1) clarification of organisational goals, (2) evaluation of existing investments and (3) innovation by application of new technology. A fourth approach strategy is to combine the three strategies in various ways. The strategies of differentiation and focus (Porter, 1985) can be used to further improve the scope of the evaluation approach.

When a discrepancy in the form of a need, problem, or opportunity is identified, further analysis can be undertaken. For this analysis, a mission statement or a project goal must be defined. A mission statement provides a long-term continuity, because it gives the organisation and its employees direction and purpose (Ishoy & Swan, 1992).

Task Analysis

Task analysis is an analysis of the final task for which training is to occur. In other words, it derives the main elements of the training content (Patrick, 1992). Without the task analysis, there can be no guarantee that the training given will not be deficient in some way (ENTWG/TT-PUB 2, 1983). In addition to the analysis of the tasks to be trained, the task analysis must also include the instructor tasks. From the Cases the task space also includes the instructor tasks. By including the instructor tasks in the task space of the planned technology-based training system, a more complete picture of the system can be created.

A *job* is the duties, tasks and sub-tasks performed by one individual (ENTWG/TT-PUB 1, 1990). Where the term *task* is any set of activities occurring at about the same time sharing the same common purpose that is recognisable by the task performer (Patrick, 1992).

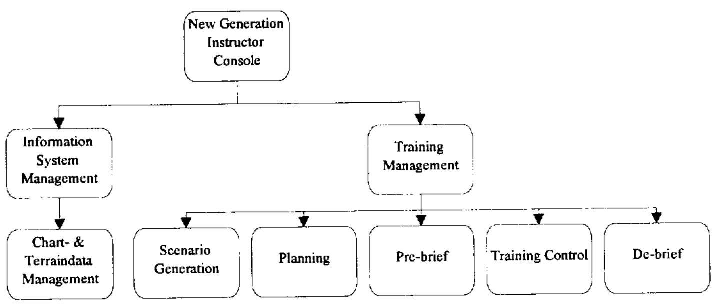

Figure 2. The task hierarchy of the scenario management system

The task can be broken down into *sub-tasks*, which are parts of a task that may not stand alone. When dealing with task analysis it is important to know what is meant by it, and how it is achieved and carried out.
The task analysis technique used in the evaluation method was based on an object-oriented approach (Bots, 1989). This technique is a combination of the critical incident technique (Flangan, 1954), hierarchical task analysis and Petri nets (Kirwan & Einsworth, 1992). The advantage of this object-oriented technique is its descriptive as well as its prescriptive way of illustrating tasks and sub-tasks (Bots, 1989).

Figures 2 and 3 give a high level description of the tasks of the scenario management system of Case 2. Figure 2 illustrates the task space. Figure 3 illustrates the relationship between the different sub-tasks. This object-oriented task analysis technique may help to reduce differences in terminology and create a common ground for understanding evaluating technology-based training systems.

Audience Analysis

Analysis of the trainees will vary from an analysis of main features and down to a detailed analysis of the individual trainee (UD 3-2, 1984). The nature of the trainees must be determined and their skills assessed (ENTWG/TT-PUB 2,

1983). The first decision to be made, is how much information is necessary for an adequate audience identification or analysis. An analogy to conduct an audience analysis is found within product marketing (Moller & McDermott, 1992). Following this idea, the trainees or target audience can be divided into different clusters (Kotler, 1994). Clustering of the target audience can be done after different criteria.

In Case 1 the target audience was clustered after its respective organisations. Some of these organisations were Navy and Coast Guard vessels, and coastal fortresses. These organisations are situated at different locations which implies a target audience scattered

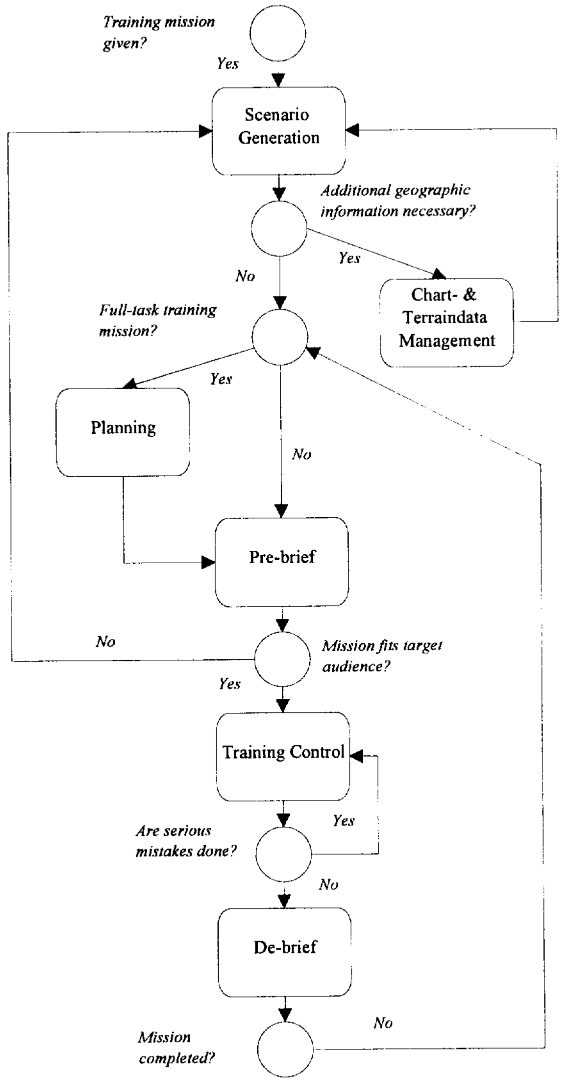

Figure 3. The scenario management task.

over a geographical area. Considerations about the access to different clusters of the target audience must be done when evaluating technology-based training systems.

Further, the target audience can also be clustered after their respective training courses and career programmes. When the clustering of the target audience is done the assessment of the trainees characteristics can be performed.

The target audience analysis will account for the users of the system for which training is to take place. It is necessary to know at what stage the trainees enter the training process (i.e. what skills, knowledge and attitudes they possess prior to

training Burniston & Tayler, 1995). This is important because a technology-based training system can be used for both initial training and continuation training (NIAG(94)SG/45-R4, 1994). In the Royal Norwegian Navy technology-based training systems were applied on three main levels of training. These were the training of (1) individual, (2) team and (3) command operations (RNoN NSST, 1995).

Competence Contribution

Competence is the skills, knowledge and attitudes required to perform an operational task. Different technology-based training systems may differ in meeting operational competence requirements. To evaluate this competence contribution, training objectives have to be defined. A training objective can be seen as an expression that emphasizes what the technology-based training system must be able to support for training to occur. Subsequently, these training objectives are statements of new competencies the trainee should possess at the completion of training to meet operational competence requirements (Russel, Molenda, & Heinich, 1993).

To determine the training objectives structured guidelines are available. One way of detailing training objectives is by means of the convention called the *five-component objective* (Gagné et al 1992). The five-component training objective specifies elements such as the situation, required competence level, specific actions, tools and constraints (Gagné, 1992). Well-defined training objectives are essential when determining the training method to be used.

The training objectives can also be used to gain information on the training system's temporal aspects. In Case 1 the following questions were asked. In what time perspective are the training of these tasks valid? Further, will changes in the operational organisations in the near future have any impact on the training objectives? Temporal analysis is important for the future effectiveness of the technology-based training system.

In addition to the training objectives in Case 1, instructor objectives were defined. The instructor objectives were also a natural element in Case 2, to pinpoint the instructor's needs in the training process. The training and instructor objectives are used to evaluate different technology-based training system investment strategies. The different strategies may range from simple to complex systems solutions.

Training Commitment

Organisational readiness analysis is performed in the Training Commitment stage of the evaluation method. It examines the commitment by the subject matter responsible organisation to implement the proposed technology-based training system into its training programmes.

In Case 1 an important issue was improving the utilisation of existing technology-based training systems within the RNoN. An aspect of this improved utilisation is how the planned technology-based training system fits into the existing and future training courses and programmes. Decisions on including the system in the different training programmes were up to the subject matter responsible organisation and not the service provider department. For the subject matter responsible organisation it can be a question of convenience and practicality before the issue of training effectiveness. Training effectiveness is the best utilisation of resources available in bringing the trainees or target audience up to the required standard (ENTWG/TT-PUB 1, 1990).

Applications

This stage covers the transformation of revealed training and instructor objectives into an environment for application delivery solutions in the form of technology-based training systems.

The man-machine interface (MMI) is the way the trainees and instructors communicate with the technology-based training system. Therefore it is important that the MMI provides the necessary cues for training to occur (Burniston & Taylor, 1995). In the two Cases the MMI were windows-based. In Case 1 the MMI emulated the functionality and presented the image of the operational communication equipment. The purpose-built hardware implemented were the different types of telephones resembling the operational parent equipment. The evaluation of man-machine interface becomes more difficult when considering more complex technology-based training system solutions. Here in addition the MMI can be purpose-built hardware to replicate the operational equipment, as in Case 1. The reproduction of kinaesthetic cues, visual images and audio must also be included.

A technology-based training system may consist of different software modules. In both Cases different system modules were defined such as database management systems (DBMS), scenario generation and simulated entities. Other system modules used in a technology-based training system can be geographical information systems (GIS), and modelling and animation tools. In addition to these software modules the operating system software must also be evaluated. In the two Cases both client and server operating system software were evaluated.

Data Needs & Requirements

Data forms the basis of every information system. The most important issue here is to determine the data structure and the most important data-elements (Eilers, Dijkstra & Hoven, 1991).

In Case 2 a database design was developed to reveal the data foundations required by the system. This database incorporated elements such as scenario descriptions, configuration and model parameters, charts organisation and trainee information. Other data elements considered were charts and terrain information available on standard data formats. Respectively formats such as DX-90, digital terrain elevation data (DTED) and digital feature analysis data (DFAD) (RNoN NSST, 1995).

In Case 1 and Case 2 evaluation of data elements that must be exchanged with other existing or planned technology-based training systems were also undertaken.

Computing & Communication

It is necessary to perform analysis of the required computing architecture of the technology-based training system. This provides an insight into the ability of a particular technology-based training system's architecture to meet performance requirements. The computing architecture of technology-based training systems may range from a collection of elements such as image generators, audio systems, kinaesthetic control systems, specific-purpose built components and scenario management work stations, to personal computers in a network or stand-alone solutions.

In the Cases, both the internal communication network and the external integration with other technology-based training systems were evaluated. In Case 2 the system operated in a distributed environment with a local area network as central communication media. In addition it was supposed to exchange information with other systems by means of a distributed interactive simulation (DIS)-gateway.

People & Procedures

To implement the technology-based training system a set of procedures are required. These procedures or management activities differ with the life-cycle state of the system (Looijen, 1991). In both Cases management procedures were outlined.

In Case 1 the management of the technology-based training system was to be carried out with the existing staffing level. Human recourse evaluations are required for the fulfilment of these management procedures which are necessary to keep the training system operational. The method supports the evaluation of required management procedures and staffing considerations for technology-based training systems.

Cost Analysis

To gain insight into the financial aspects of technology-based training system cost analysis must be undertaken. From the Cases the initial investment cost was identified. Further in Case 1 the life-cycle cost was estimated for the different investment strategies. The initial costs can be divided into two categories (Lien & Bjørn, 1995). First all the costs related to the planning and accomplishment of the project and then the second category covering all the costs concerning the procurement of software, data, hardware and facilities. The life-cycle costs regards all costs associated with the training system's maintenance and management activities.

CONCLUSION

The effectiveness of a technology-based training system is whether or not it meets well defined objectives that are based on the needs and constraints of its ownership organisation. The method suggested in this paper can be a helpful means to evaluate this effectiveness.

By means of the evaluation method different investment strategies for technology-based training systems can be outlined. These different investment strategies can be illustrated by means of an evaluation matrix (Berghout, 1994). The vertical and horizontal axes portray, respectively, the training and technology value of the investment strategy. The area of the circle reflects the initial and life-cycle cost.

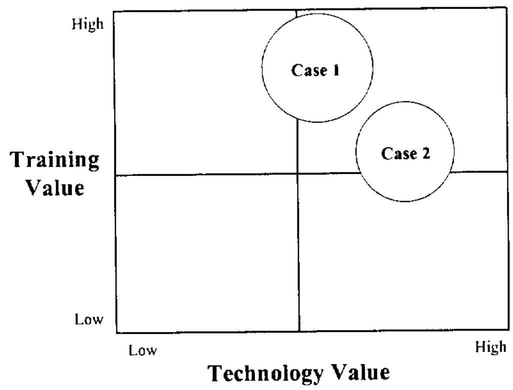

Figure 4. The investment strategy evaluation matrix (Berghout, 1994).

The *training value* of a technology-based training system is its effectiveness, efficiency and relevance to the operational task, as perceived by its users. The *technology value* is the strategic alignment of the information system components with organisational information plans.

Reasons for a more formal approach to investment evaluations of technology-based training systems are:

- The large sums of capital that are often involved in procurement of technology-based training systems.
- Technology-based training systems often have significant consequences for other technology investments, hence compete with other investment opportunities (Hares & Royle, 1994; Berghout, 1994).
- Formal approaches create a common ground for communication between the different parties involved in the decision process.
- Training needs and their technical solutions need to be co-ordinated.
- Increased awareness exists on training objectives and its relevance to the operational situation.
- The initial enthusiasm regarding new products tempt decision makers to overlook possible negative consequences.

The investment analysis technique that has been presented in this paper seems to provide a comprehensive evaluation of technology-based training systems.

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US NAVY AND MARINE CORPS REQUIREMENTS AND CHALLENGES: VIRTUAL ENVIRONMENT AND COMPONENT TECHNOLOGIES

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The US Navy and Marine Corps have clear requirements for virtual environment (VE) systems and related component technologies for both training and operations. VE systems have been defined broadly to include any computer-based representation of an artificial or real world regardless of the medium of display. A more restricted definition includes only those systems that rely on some form of immersive display where the user experiences and interacts directly with the virtual world as if they were part of the simulation. This paper addresses requirements and technical issues related to the latter category of immersive VE systems. Discussion will be limited to land, sea and subsurface applications without in-depth treatment of aviation and targeting requirements.

Immersive VE systems are characterized by multiple sensory modalities and direct interaction. VE displays can include head-mounted visual displays, which are yoked to head position producing the illusion of fully immersive 360-degree immersion. Head-mounted visual displays can be monocular or "see-through" permitting the observer to integrate real surroundings with virtual objects and displays. Another version of visual immersion uses projection displays on a small enclosed space allowing free head movements and natural exploration of the surrounding virtual space. The sense of physical presence created by immersive visual displays may be augmented by spatialized (3-D) audio, which can simulate the acoustic filtering of the head, pinnae and facial features as well as virtual room acoustics. Spatialized audio creates the perception of sound sources well-localized outside the head rather than between the ears as is usually the case with headphone presentation of sound. This expansion of the perceived workspace of the operator takes advantage of the human ability to attend to multiple spatially discrete information sources. As we shall see later, both virtual visual and audio have the potential for greatly increasing the personal or shared workspace of individual operators.

In addition to the better known visual and auditory virtual displays, there have been significant advances in the rendering and display of virtual haptic representations (Tan, Durlach, Beauregard, & Srinivasan, 1995; Srinivasan and Durlach; http://touchlab.mit.edu/). Haptic perception combines tactile (touch) and force-feedback (proprioceptive) and is usually associated with active motor exploration of the objects being explored. Haptic displays can be used as direct manipulation interfaces and together with automatic speech recognition help to make interactions with immersive VEs truly direct and natural. Immersive VEs can be defined by any or all of these features but most commonly are associated with temporally synchronized and spatially registered virtual visual and auditory displays.

VE systems should be considered as potentially augmenting or replacing dedicated simulator technology, especially with respect to training applications. Conventional simulators are dedicated hardware and software systems, often costing millions of dollars to acquire and maintain and requiring large spaces to house the systems physically. These size and cost constraints often limit the number of available systems and can only provide limited accessibility for a broad range of users. While these systems are often magnificent in their fidelity and potential effectiveness, more affordable and accessible simulation-based training systems are required to reach a larger training market. Reconfigurable computer-based training systems including VE are available to a larger market because of their low cost and inherent deployability. Such lower fidelity systems can be used to optimize limited time spent in more expensive dedicated simulators and may, in some cases, actually be as capable or more capable in terms of training effectiveness. Rapid advances in VE display technologies and computing power coupled with decreasing system costs will continue to improve the fidelity and usability of interactive VE systems.

VE systems have many advantages over conventional simulator systems for training and mission rehearsal. Unlike conventional dedicated simulators, most immersive virtual environment systems are compact and have the potential to be reconfigurable in software. This means that a single virtual environment interface could be used for multiple training domains as diverse as shiphandling, maintenance and flight operations.

This reconfigurability makes VE an affordable alternative. Both the compactness and inherent affordability of VE systems makes larger production runs possible and increases the potential for large-scale deployment in the classroom and in the field. The resultant increase in availability of VE systems makes training systems more accessible to more

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potential students and could optimize the limited training time spent in conventional and dedicated simulators. Technical challenges to field and shipboard deployment of immersive VE training systems must be addressed quickly as there is a groundswell of requests to deploy these systems as quickly as possible.

Operational uses for immersive VE systems outside of training and mission rehearsal are a longer-term developmental challenge. There seems to be some potential for VE as a control system for remotely-operated vehicles (ROVs) among other teleoperation applications which require a sense of remote spatial situation awareness and maneuvering skills. Performance aids have been discovered as training approaches for pilots of undersea ROVs where close-in maneuvering is a critical control feature and where current control interfaces are not well designed from a human usability perspective. Non-immersive volumetric displays such as the Virtual Reality Responsive Workbench (Rosenblum, Naval Research Laboratory) show great promise as a medium for operational planning and distributed coordination and could be augmented or replaced by personal head-mounted immersive VE technologies.

More near term operational opportunities are VE component technologies that together provide immersive VE experiences. Spatialized audio and heads-up or monocular displays have immediate value to the design of optimal human-computer interfaces by increasing the potential display real estate available to the designer and the user. We shall see later that these component technologies are already making inroads into operational Navy systems such as the advanced multi-modal watchstations and distributed integrated command environment (ICE) concepts in the SC21 ship design program (21st Century Surface Combatant; http://sc21.crane.navy.mil).

SIMULATION-BASED TRAINING: A SEAMLESS CONTINUUM

Current Navy and Marine Corps training doctrine is to "train as we fight." This philosophy leads to a scenario-based training approach that lets our warfighters experience some measure of the chaos and unpredictability of combat before they are thrown into the real thing. Scenario-based training allows a full range of experience to the warfighter from mundane to high-pressured mission rehearsal and allows the user to experience dangerous situations and attempt potentially high-risk solutions and strategies that would not be feasible in real-life training exercises.

Another implication of the "train as we fight" approach is that it is better to train in the actual operational environment with the same people and the same equipment than to train in some remote location on mockups or other degraded facsimile of the operational environment. According to this reasoning, the farther away the training experience is from the actual operational experience, the less effective will be the transfer of training to the real operational world.

These considerations have lead the Navy to emphasize embedded training systems for almost all manned shipboard systems. Onboard scenario-based embedded training systems are well placed to provide training in an operational context that facilitates training transfer. Because of their inherently deployable nature, embedded training systems can also provide just-in-time refresher training or mission rehearsal as needed driven by emerging mission requirements. Embedded training systems must also be designed to diagnose training needs of individuals and teams through computer-based monitoring. This information has the dual advantage of providing feedback to shipboard instructors as well as forming the quantitative foundation for a performance-based measure of personnel readiness required in a reduced manning force. Timely information about operational skills is absolutely essential for intelligent management and optimization of limited personnel resources. Shipboard embedded training systems do have the potential to greatly reduce the shore-based training infrastructure and may provide some long-term affordability benefits.

Embedded training approaches do have a potential downside. Operational requirements and training requirements can often conflict restricting the availability of training opportunities. This restricted availability is compounded when the training exercises require multiple team members, making it even less likely that everybody will be available without taking the operational systems off-line. Shore-based training resources are being reduced to save money and to streamline the training pipeline. Given this trend, additional stand-alone training capabilities are required to augment and support the increasing dependence on embedded training systems. More pierside and shipboard training opportunities are needed.

Stand-alone simulation-based training systems can complete a seamless training continuum from shore-based schoolhouse and pierside training to onboard systems including stand-alone and embedded systems. Simulation-based systems can emulate the operational environment including both equipment and virtual team members and adversaries. To the extent they are successful at emulating operational systems in terms of functional and physical fidelity, they will have similar benefits to embedded systems. Hypothetically, it should not matter to a student fully immersed in a stand-alone training system whether the system is deployed in the schoolhouse, pierside or onboard. Stand-alone onboard systems will have the additional advantage of allowing accessible just-in-time training tailored to the needs of the individual without conflicting with the operational requirements of the ship.

Stand-alone simulation-based training can be delivered at multiple levels of physical and functional fidelity, from interactive courseware on CD-ROM to fully immersive virtual environments. These computer-based systems have the advantage of being reconfigurable in software so that a single delivery system can serve a broad range of training domains. Critical task analyses and studies of training effectiveness must focus on the conditions under which a specific training delivery approach is warranted and cost effective. As display and interaction technology improves and costs decrease, fully immersive VE displays will become commonplace and affordable. It is important to begin to define the acceptable boundary conditions for use of immersive VE systems deployed ashore and afloat. Critical factors to consider include effects of platform motion, field of view, update delays and duration of immersion on physical symptoms of sensorimotor adaptation.

NAVAL SHIPHANDLING REQUIREMENTS

The US Naval Air Warfare Center, Training Systems Division (NAWC-TSD), with the sponsorship of the Office of Naval Research (ONR) has been addressing the needs of the surface and subsurface Navy in shiphandling and harbor piloting with immersive VE training systems. In the submarine community, harbor piloting is an infrequent but critical mission function with few training opportunities. While there is an existing below-decks team trainer (Submarine Piloting and Navigation or SPAN), conventional simulator technology was considered too expensive to provide an immersive visualization capability for the critical leader of the submarine navigation team, the officer of the deck (OOD). The ONR-supported 6.2 exploratory development program in virtual environment training technology (VETT) produced a prototype submarine shiphandling trainer that has transitioned to the 6.3 VESUB program (Hays) and is currently in its third year of funding.

This successful development of a VE training approach to submarine shiphandling has led the Office of Naval Research, NAWC-TSD and the Surface Warfare Officers School (SWOS) to evaluate the related training requirements of the surface warfare community. SWOS has identified the need to augment or replace existing dedicated simulator training capability that costs the Navy in excess of $2M/year to maintain and suffers from the drawbacks in availability outlined above. The possibility of compact and deployable VE systems is consistent with SWOS' vision of a seamless training continuum that could include other shore-base facilities where a stand-alone system could help sailors maintain their shiphandling skills while on extended shore duty or during sea-going deployments. Department Head training at SWOS has been identified as the primary target of the new VE shiphandling systems. Critical task analyses and experiments are underway at SWOS, NAWC-TSD, MIT and elsewhere to define specific training objectives, curriculum and instructional approaches that enhance the training effectiveness and usability of proposed simulation-based systems. Operational challenges being addressed in the near term include underway replenishment (UNREP), plane guard and harbor transit. Technical challenges include understanding "seaman's eye" at a perceptual and cognitive level, ship hydrodynamics and interactions as well as the human-computer interaction (HCI) design guidelines for the development of usable VE systems. Of particular interest is the value added of immersive VE interaction versus more conventional desktop approaches.

URBAN WARFARE REQUIREMENTS

The US Marine Corps has identified training for urban warfare as their highest priority. Urban warfare is the bloodiest, most casualty-intensive warfighting challenge facing our military services today and training the high-level skills required to be effective in these difficult combat scenarios is of critical importance. The Marines are strong proponents of the simulation-based approach to combat training and have instituted a series of large scale distributed training exercises (Hunter Warrior, Urban Warrior and Capable Warrior) to evaluate new methods of distributed team training and operations, with a special focus on small unit operations.

One example of distributed urban warfare training is a Marine Corps project being developed at NAWC-TSD called Small Unit Tactical Training (SUTT). Training objectives and HCI technical challenges of this effort include marksmanship, house-to-house search, person-to-person nonverbal communications and global spatial situation awareness of individuals and team members for immediate search planning and execution. Ultimately these training modules will allow distributed team training across sites that are widely distributed geographically. The Marines would like to see this capability developed for shipboard mission rehearsal while underway on combat deployment. Similar training and mission rehearsal capability would be useful for Special Operations forces.

The current SUTT simulation approach uses a single screen back projection technique with no head-mounted display and a relatively artificial locomotion interface and speech input system. One advantage of this system is that it allows the integration of marksmanship to the urban warfare training objectives. Potential drawbacks to this approach are that spatial situation awareness must be reconstructed in a very unnatural way that could impede the development of individual and team tactical skills. With the single screen projection approach, the user can only see into the virtual world through a single screen like a picture window in front of the viewer. In order to look to the side, users must artificially swing the world around to the front by turning their head and body more than 45 degrees to the desired

viewing direction. This unnatural and perhaps maladaptive motor behavior conflicts with basic proprioceptive and vestibular sensory input and creates an inconsistent mapping of the local virtual environment orientation with the global coordinates of the real world the user can still see and feel around him. At minimum, the control and display interface is a distraction and additional information overhead for the user. At worst, such a display interface will disrupt the very spatial orientation and situation awareness that the system is meant to train.

There are a number of possible technical approaches to the SUTT spatial situation awareness training objectives. Immersive visual displays including head-mounted displays (HMDs) and immersive room environments (e.g., CAVE) would provide a complete 360 degree perspective that would not produce conflicting spatial awareness cues to the user. The HMD solution has the added benefit of compactness and deployability but presents a further technical challenge when the marksmanship requirement is added to the training requirements. The immersive room environment potentially could address the marksmanship requirement as well and new technologies could be developed to reduce the footprint of the immersive room. In addition, researchers at the US Naval Research Laboratory in Washington, DC, are developing and evaluating a more natural and easy to use locomotion interface that would reduce the information overhead required to use all of the simulation-based training concepts described above (Templeman).

REMOTELY OPERATED VEHICLE REQUIREMENTS

Remotely Operated Vehicles (ROVs) are unmanned air, land or sea vehicles that are teleoperated by human users at a remote location. The primary benefit of teleoperation is the projection of human skill or intelligence into a potentially hazardous remote environment. Some technical challenges for ROV operation are developing a spatial awareness of the remote environment of the vehicle and developing a vehicle control capability that includes maneuvering and, in some cases, telemanipulation. Virtual environment simulation for teleoperation can provide a seamless 360 degree reconstruction of the remote environment that could actually be an improvement over having a human observer directly at the site. For example, undersea ROVs are often used at extreme pressures in cold, dark, silty ocean environments that would be extremely hazardous or impossible for human divers. Multi-sensor fusion (visual, IR, sonar, force feedback) can support reconstruction of the remote scene that would be better that the limited visual inputs of a diver on the site.

Undersea ROVs address military requirements in mine countermeasures and submarine rescue as well as commercial and military needs in search, salvage and inspection (hulls, undersea oil rigs and pipelines, etc.). There is a scarcity of experienced Navy ROV pilots and a large turnover of competent pilots makes ROV pilot training a major training requirement for this community.

A consortium of industry and academia researchers (Imetrix Inc., Boeing, GTE, and MIT) supported by ONR is addressing this requirement in the TRANSoM (Training in Remote Sensing and Manipulation) project. The TRANSoM team has developed a stand-alone maneuvering skills trainer for pilots of undersea ROVs using on-line intelligent coaching that tailors instruction to fit the needs of individual students. Current efforts are looking at extending the training to spatial situation awareness (including tether management) and the relative value added of immersive versus conventional desktop displays.

VE COMPONENT TECHNOLOGIES

Many of the technologies developed for immersive VE systems will find near term application as non-immersive augmentations to existing or planned operational environments. As discussed earlier, head-mounted visual and audio displays can greatly extend the perceived workspace of an operator, taking advantage of the human capability to attend to multiple information sources that are spatially distinct. This expanded display space can be used in the design of consoles that optimize information management and workload. Volumetric information displays can improve global spatial awareness and might be valuable to provide a common picture for distributed interactions among geographically separated team members, reducing the communications overhead of team interactions. Personal portable displays can provide decision support where and when it is most needed. For example, "see-through" or monocular display approaches might be able to superimpose technical schematics on a specific mechanical system during routine maintenance, diagnosis and repair.

One example of VE component technology aiding operational design is in the advanced multi-modal watchstation being developed by Dr. Glenn Osga and colleagues for the ONR-funded SC21 Manning Affordability initiative. One objective of this program is to reduce AEGIS Combat Information Center manning by at least 50% through the use of human-centered design principles. The SC21 program office has conservatively estimated that success in this program objective will reduce at least 23 billets per ship providing a cost avoidance of more than $1.3B over the expected life cycle of the ship class. Osga and colleagues plan on exploiting head-worn displays and spatialized audio to expand the perceived workspace of the combat systems decision-makers. The multi-modal watchstation design can be used for

other knowledge domains across the ship including damage control and maintenance decision-making and in the design of human-machine interfaces for other ship classes using similar human-centered design principles and VE component technologies.

A larger vision for VE component technologies is found in the DD21 Integrated Command Environments of the SC21 program office (http://sc21.crane.navy.mil). In this vision of cooperative distributed decision-making, multiple individual decision-makers will communicate with the use of personal display systems similar to the advanced multi-modal watchstation. It remains to be seen whether fully immersive virtual reality simulations will ultimately play a role in recreating a shared decision-making environment across geographically distributed teams.

SUMMARY

Current military requirements for simulation-based training and optimized personal displays provide a compelling opportunity for implementation of virtual environment technologies. Near term applications for VE include land, sea and air training systems that will ultimately be used in a geographically distributed fashion for team training, mission planning and mission rehearsal. Stand-alone training systems will complete a seamless simulation-based training continuum from the schoolhouse to pierside and shipboard, augmenting the current Navy and Marine Corps emphasis on embedded training in operational systems. Virtual environment training systems have the great advantages of compactness, deployability, software reconfigurability and affordability when compared to conventional dedicated simulator systems. These advantages will lead to more widespread and available training capability. Careful task analyses, human-centered design principles and methods and better performance metrics will be needed in order to meet these emerging requirements. A continuing challenge for VE training systems is to demonstrate the value added of immersive versus more conventional desktop delivery systems. Further work needs to be done to evaluate the potential for shipboard VE systems and safety guidelines for their use. However, with the rapid advances in display technologies and computing power in industry today, we can expect VE technologies to continue to grow in value and availability as we enter the next century.

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TRAINING MINIMAL ACCESS SURGERY SKILLS WITHIN A VIRTUAL ENVIRONMENT

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ABSTRACT

A training system for Minimal Access Surgery (MAS) has been developed by the Centre for Human Sciences, part of the Defence and Evaluation Research Agency. The system consists of an object model database which can be interacted with via simulated MAS surgical tools. It is based on two low cost networked personal computers and linked to a pair of laparoscopic tools to provide accurate force feedback within a virtual environment. Development of an integrated training system forms a necessary part of delivering an effective training tool. A hierarchical task analysis (HTA) has been used to determine the key skills demanded of the surgeon in laparoscopic ectopic pregnancy. The experimental evaluation of system features to enable cost benefit trade offs to be made is discussed. From the HTA and a review of the literature new conclusions about the fundamental nature of the tasks to be trained in MAS are presented. The conclusion that adaptation to a continually varying control law is the fundamental task to be trained in MAS has implications for the design of MAS training systems.

A future programme of experimental trials work on the simulator design parameters of force feedback, scene detail and 3-D, and the application of Distributed Interactive Simulation (DIS) networks, being carried out in conjunction with the Surrey RCS MATTU unit and Loughborough University is discussed.

INTRODUCTION

The DERA Centre for Human Sciences has a background in developing and evaluating simulation for military sponsors and has recently developed a training system for Minimal Access Surgery (MAS). The system VISTA (Virtual Interactive Surgery Training Aid) has been described in previous papers (Kelly & Beagley, 1997) and consists of a novel hardware platform which includes a deformable database, viewable in 3-D, which can be interacted with via simulated MAS surgery tools which have simulated low force feedback (Figure 1). Over the course of the VISTA systems development a small number of similar systems have been developed by universities, medical research laboratories and industry, with many common features. However a number of issues remain to be addressed by this (and other) systems before they are fully taken up by the medical world, and these are discussed below.

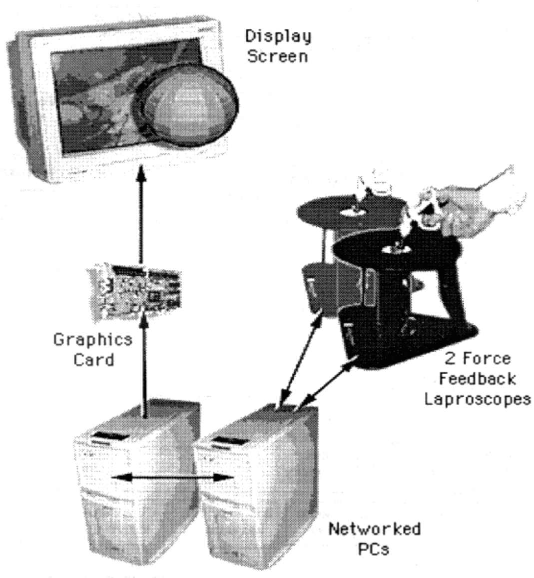

Figure 1.

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Paper presented at the RTO HFM Workshop on "The Capability of Virtual Reality to Meet Military Requirements", held in Orlando, USA, 5-9 December 1997, and published in RTO MP-54.

Training System Requirements

In an ideal world one should first have an application in mind and then design a system to meet the application needs, based on an analysis of the applications requirements, with the design features optimised for this, or a limited set, of applications. Systems designed to be all things to all men are rarely cost effective solutions. However technological advancement does not usually proceed like this. Most virtual surgical environments have moved from a technological concept demonstrator to retrospectively define an application. The best systems have a narrow application focus (e.g. training surgical procedures) the less satisfactory systems offer a wide range of applications (e.g. surgical planning, surgical rehearsal, skill training, and operative support). The value of developing the system design based on a thorough analysis of the application, and of selecting design features to provide maximum cost benefit for the chosen application is demonstrated by the approach taken for the design of VISTA.

Task Analysis

The application focus for the VISTA system is training MAS skills, using a cost effective training system. To identify the requirements for the training material an analysis of MAS skills was carried out (Shepherd, 1989) using Hierarchical Task Analysis (HTA). This focused on the surgical procedures relating to the condition of ectopic pregnancy. This is a relatively common condition which is potentially life threatening (Graber, Allen, Levy, & Talley, 1994). Treatment is predominantly surgical and is an area where MAS has made an important impact. The analysis was constructed through interview with surgeons. One of the resulting diagrams is presented in Figure 2.

The training tasks represented within VISTA include synthetic representations of the basic skills batteries that are employed by a number of MAS training hospitals (e.g., Rosser, 1995). However the HTA, along with observations and discussions with surgeons has enabled us to identify an additional basic skill component of MAS that is not currently part of the skills training in many hospitals and which has important design implications for any simulator that may be used to train these skills.

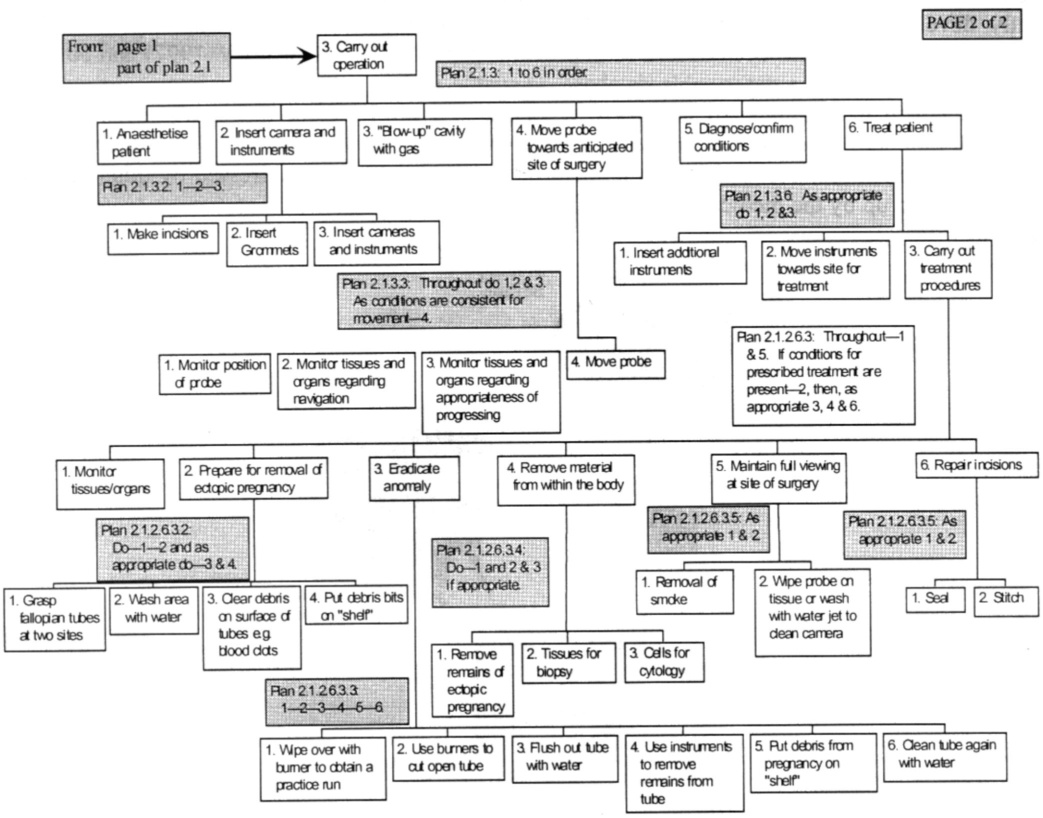

Figure 2. Part of HTA Decomposition.

Initial consideration of the unusual working environment of the minimal access surgeon suggests that they must be able to rapidly model and adapt to a variable control law. That is the relationship between their hand movements and the displayed control (Laparoscopic surgical tools) movements can continually change from moment to moment as the camera's position, orientation and FOV is changed. This may be the most fundamental skill difference from conventional open surgery techniques. The surgeon is continuously sampling the environment, modelling the CD relationship and confirming the model by test movements. An example of such a test movement can be seen in the lower level HTA task (plan 2.1.2.6.3.3; task 1) "Wipe over with burner to obtain practise run". Therefore it is a design requirement of a basic MAS skills trainer that the camera position can be controlled and varied during a training task. This feature cannot be found on some skills trainers which arguably limits their training value. Pilot studies on the rates of learning MAS skills in a virtual environment with and without variable camera position have been carried out using the VISTA system (Raynor, 1997). These confirm that the skills learnt in a variable camera position regime transfer better to a criteria task, than when learnt with a fixed camera regime, and that when MAS skills were learnt in a fixed camera regime interference was found on transferring to a criteria task.

Design Trade Offs

Developing a cost effective solution was also supported by taking a modular approach to the technology. All elements of the development system were hosted separately to enable their contribution to the overall systems training effectiveness to be assessed and optimised. The final design solution could then be packaged as a single platform solution using hardware and software solutions that would be state of the art at the time of delivery. The contribution of features to the overall training effectiveness of the system was the basis of the supporting experimental programme. Systems exist which enable force or tactile feedback to be implemented in a virtual surgical simulator (Immersion, 1997), however it is the sophistication of the underlying mathematical model of tissue deformation which makes this task easy or difficult to simulate. Accurate implementations of force feedback are a high cost driver and may offer low benefits at the basic level of MAS skill acquisition. The main areas to be evaluated for their contribution to the training systems effectiveness are given in Figure 3.

FUTURE RESEARCH ISSUES

The main research issues we are concerned with can be grouped into three areas; the hardware issues, the ergonomic issues and the training media and method issues.

Feature	Cost	Technical difficulty	Training benefit
3-D	Medium	Low	Unknown/Low?
Force Feedback, Simple Algorithms	Medium	Medium	Low?
Force Feedback Advanced Algorithms	High	High	Medium?
Polygonal Organ Models	Medium	Low	Medium
Voxal Organ models	High	High	Low?
Performance measurement	Medium	Low	High
Skill based tasks	Low	Low	High
Variable camera Position	Medium	Low	High
Olfaction	Medium	Medium	Low?

'?' indicates areas for further research

Figure 3. Simulator Features for Design Trade Offs

Hardware Research Issues

There are two main areas in the development of the hardware on which SME's appear to differ; these are the requirement for 3-D and the requirement for force and kinaesthetic feedback. This difference of opinion may be because of some difference in the applications which the SME are concerned with, or differences in the training and execution of the surgeons skills (and the cues they are accustomed to using). Or it may be confusion or unfamiliarity with the potential of

each of these technical possibilities as opposed to their limitations. It is clear that both 3-D and Force feedback are issues requiring further research.

Force/Kinaesthetic Feedback

Many surgeons say that any MAS training system must have force and kinaesthetic feedback for the surgical tools. But it is clear that one of the problems in this environment is the low levels of force feedback present which can be exacerbated by the flexibility, damping and adsorption of the surgical tool being used.

The high cost of force feedback in the system meant that its contribution to training effectiveness was one of the first areas to be addressed. Pilot studies (Kelly & Cotter 1998) have indicated that the simple model for force feedback implemented in VISTA can have a beneficial effect on the accuracy and speed with which a training task is performed in the system.

3-D

Early MAS systems did not have colour displays and few now have 3-D. Technology is now able to offer 3-D to the MAS surgeon and it is likely that unless there is a strong reaction to it 3-D displays will form part of future MAS surgical suits. Nonetheless the benefit from its use is still unclear, and while lightweight headsets that still allow a degree of peripheral and local normal vision are now available, some surgeons still find their use uncomfortable and restricting. It is clear that many MAS tasks require depth perception but it is also clear that depth cues are present in normal displays (e.g. shading, shadows, occlusion etc.) and that not all surgeons benefit from enhanced 3-D. There is some evidence that two-handed tasks can be carried out faster using 3-D, but the conclusive research remains to be done. VISTA has a selectable 3-D output to enable the contribution of the 3-D displays to training effectiveness to be researched.

Ergonomics

The variety of designs of MAS systems available for surgeons indicate that there is still a need for some basic ergonomic studies on relative screen, body, and hand positioning, and to consider the possibility in some cases of seating or supporting the surgeon. Studies of operating theatre team interactions are being carried out (Helmreich & Schaefer, 1994) and VISTA has been sourced to provide the operational task in these studies.

Training Media

The development of Objective Performance Measures (timings, error rates, positioning and placing accuracy – see, Johnston, Bhoru, Satava, McGovern, Fletcher, Rangel, & Loftin, 1995) to support the traditional subjective assessment of performance normally found in surgical training is seen as a key area of research for MAS. Objective Performance Measures (OPM) will be developed using the analysis of MAS skills and additional information from SME interviews and the examination of current training practices. These measures support the setting of training performance standards and aid in the provision of feedback during skill development. It is also seen as important that the training material is based on the training analysis and on existing training theory. This is to ensure that training is effectively structured, with appropriate sequencing, level of exercise detail and feedback. This will lead to the development of a series of training tests that can aid in the development of an auditable training trail for MAS.

CONCLUSION

It is clear that the new surgical procedures of MAS offer many advantages for patient care and that technology offers a degree of solution to the training problem.

Computer based simulation provides an opportunity to extend the current approaches to MAS training. Simulation of the surgical environment combines complete control over the training task with the means of gathering objective performance data.

The rise in litigation in this area has led to demands by surgical training organisations for an accredited, structured and validated training programme for MAS, based on Objective Performance Measurement, that can provide a defensible audit trail for MAS competence. The degree to which technology provides a solution to the training problem and the

exact benefit of all or each of the technical possibilities in this new field is the focus for further research in this programme. This paper has presented the initial work towards the integration of an interactive virtual environment with a theory based training structure, grounded in the analysis of MAS procedures. In doing so, it has raised some fundamental issues relating the skill elements that underpin MAS.

We believe that a skills trainer that is cost effective can be built, but that a system for full surgical simulation whilst possible technically is still too costly for the basic surgical training market place. It is likely that any surgical training centre would eventually have a range of training systems each with differing amounts of technical sophistication, catering to basic training, advance skill training and full surgical simulation.

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UK MILITARY REQUIREMENTS FOR ROBOTIC LAND VEHICLES

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This presentation describes the operational requirements and methods of achieving remote operation of Combat Engineer Equipments for use by the UK Army during periods immediately prior to combat, possibly during combat and extensively in battle area clearance operations. The techniques can also be used in peace support.

The paper examines the teleoperational requirements for the adaptation of existing Combat Engineer Vehicles such as the Chieftain Armoured Vehicle Royal Engineer (CH AVRE) also known as AVRE tank, and the Combat Engineer Tank (CET) and future requirements for service replacement vehicles such as Future Engineer Tank (FET) and Terrier (replacement CET).

The UK sponsor for this work is the Ministry of Defence, Main Building, Whitehall, London. I would like to thank Lieutenant Colonel Philip Poole, SO1 Engineer, DDOR (Engr&NBC) for assistance in offering advice and material on User requirements.

DERA Chertsey LS4 department is currently conducting applied research in support of the UK MOD programme for Combat Engineer Equipments and Robotic Land Vehicles.

INTRODUCTION

Unmanned ground vehicles have applications on the battlefield, for example in reconnaissance and mine clearance, where their use reduces danger to men. In this presentation, teleoperation and the technologies involved are discussed using examples of successful demonstrations. Current technology can already enable manned vehicles to be converted to remote operation for tasks where men would be particularly endangered. The introduction of unmanned ground vehicles (UGV) technology should therefore be evolutionary, with the aim of developing vehicles which have greater intelligence, independence and versatility, and which could save manpower at favourable costs.

The idea of robots on the battlefield will conjure up, to many, visions of large-walking creatures roaming free and destroying everything they encounter. Whilst the battlefield use of robots of such sophistication is still a long way off, UGV's of more limited capability are already making an important contribution to the modern army: UGVs are now widely used for explosive ordnance disposal (EOD) tasks, and have been used in this role for over 20 years.

Some advantages of using UGVs instead of manned vehicles are:

- Reduced risk to man (since destruction of an unmanned vehicle does not result in the loss of the driver and crew).
- The possibility of bolder concepts of operation, because of this reduced risk. Higher performance levels on extended and repetitive operations (where, for example, humans may suffer from fatigue, boredom or stress).
- Manpower reduction (as robotics compensate for a reduction in manpower without loss of effectiveness).

Conversely, disadvantages of the vehicles are:

- Their high cost.
- A lack of user confidence, acceptance and an increased logistic burden. UGVs are probably less flexible and adaptable than men.

Paper presented at the RTO HFM Workshop on "The Capability of Virtual Reality to Meet Military Requirements", held in Orlando, USA, 5-9 December 1997, and published in RTO MP-54.

User Requirements

Over the years, the need for, and scope of, Engineer support on the battlefield has been well established. It is provided by a wide variety of equipment and vehicles, optimised for their specific role and place on the battlefield. Engineers have, and will continue to use, a number of armoured vehicles to provide mobility, counter mobility and survivability support to formations whilst providing protection to their own crews. Combat Engineer Tractor (CET), Engineer tanks, the AFV 432 and CVR(T) all fulfil vital functions within Engineer regiments. It is planned to replace all of these vehicles in the next 10 years.

The current Chieftain Armoured Vehicle Launched Bridge (CHAVLB) and Chieftan Armoured Vehicle Royal Engineer (CHAVRE) were converted from Chieftain gun tanks in the 1970s and 1980s respectively, to replace their Centurion based predecessors. Experience gained on operations and in training and Operational Analysis have highlighted a major deficiency in the mobility of Chieftain Engineer variants when compared with the more agile armour that they support. This deficiency was exemplified on Op GRANBY (Gulf War) when Engineer vehicles fell behind between 3 and 6km, for every 10km advanced. The replacement of both vehicles will be carried out with Future Engineer Tanks (FET) having an in-service date of 2002/3 and the replacement of CET with the Terrier vehicle in 2006/7 will enable Engineers to provide improved close mobility support to armoured formations.

The mechanisms of Engineer Support, Engineer tasks on the battlefield involve mobility, counter mobility and survivability support. Tasks are undertaken throughout the width and depth of the area of operations, and are provided by a range of equipments with complementary characteristics and capabilities. Engineer mobility support tasks include wet and dry gap crossing, obstacle breaching, route opening, route maintenance, countermine and EOD battlefield clearance. Mobility is denied to an enemy through the enhancement of natural obstacles, the construction of man-made obstacles and the blocking of routes. The ability rapidly to construct earthworks and defences for all-arms protection is an essential part of survivability support.

It is the aim that the Robotic Land Vehicles research programme will help to enhance the Royal Engineers and other arms capability by improving mobility and counter mobility support to armoured formations.

Direction of UK RLV Programme

Two of the equipment types are discussed here where DERA have to date conducted research into teleoperation for remote driving and engineer tasks. Other applications for other Engineer vehicles will be likely in the future. The need for teleoperation techniques will most likely be in colour and contain elements of mono/stereo vision, augmented reality, virtual reality (VR) or a combination.

The programme has so far been concentrating on teleoperation kits for in-service vehicles such as the CHAVRE and the CET. It is seen as the most likely route for robotics to enter service and gain user acceptance. Acceptance of new technology equipments has always been a challenge to the researcher and the growing requirement these days is to show that the benefits to the user outweighs the cost of development.

We are currently investigating technologies that will improve teleoperation capabilities - these are stereo vision, optical flow, communications, image compression and augmented reality techniques.

Design Philosophy

The philosophy for the core area of the DERA research programme has been to take the latest available technology and assess its capabilities for the users requirement. Urgent operational requirements (UOR) occur from time to time. By assessing the latest technologies/equipments, rapid responses can be made when the need arises to provide appliqué kits for UORs.

The use of such kits allows flexibility where the kit can be removed reasonably quickly from the vehicle and it can then be interfaced with another type of vehicle. Commercial off the shelf equipment is used wherever possible. There must be no interference with the manual operation of the vehicle and a short change over time from manual to remote control by, for example switched operation. Design concepts must be space conscious as the controls and interface units must fit into already cramped spaces in the Engineer vehicles. Operator Control Units are required to be fitted into the secondary

vehicle. Space is an important consideration and the use of Helmet Mounted Displays or VR systems may help to alleviate this problem.

A recent injection of finance into the research budget has allowed the direction of the programme to investigate future teleoperation techniques such as novel vision and augmented reality for teleoperation.

Teleoperation Kit For Chieftain AVRE

Appliqué kits for possible UOR use in Bosnia and also as proof of principle for future FET and Terrier programmes were investigated in 1995/96. The system currently being used in the US SARGE programme was purchased and minor modifications were made to suit the UK MOD requirement. The AVRE mineplough and fascine operations were tested, using monovision teleoperation to drive the vehicle remotely and carry out the manipulative tasks. Other areas for consideration for teleoperation are, use by a single operator, selection of cameras and camera positions, the use of a microwave link for a line of sight video transmission from AVRE to the remote command vehicle.

Three cameras are fitted to the front of the vehicle and one at the rear. The centre front is mounted above the driver's head which improves forward vision by reducing obscuration by the ploughs. Two side cameras improve side/peripheral vision and allow accurate driving within narrow lanes or fenced off areas such as minefields. The rear camera allows accurate and fast reverse driving. Operator control units can be fitted to display single or multi image options.

Teleoperation Kit For Combat Engineer Tractor

Teleoperation for CET has been based on the methodology and hardware used on AVRE. From the AVRE trials, driving functions were not difficult, thus the CET research has been aimed at investigating and improving the manipulative tasks. Trials were conducted in spring 97. The main technical objective was to investigate digging tasks required in earth moving, the construction of obstacles such as sand banks and tank ditches. Clearance of obstacles was investigated, for example, filling in NATO standard tank ditches. Other clearance activities require the removal of heavy obstacles. For this, the CET 4-in-1 bucket is ideal for these manipulative type tasks, but not easy to implement because of limited visual perception. To carry out these tasks, camera positions and the numbers of cameras must be considered.

Operator Control Unit And Its Functions

The OCU unit was selected for its history of performance use on the US SARGE programme. In the UK research programme, it is used to perform driving and manipulative tasks. It can be purchased from Omnitech Robotics or Robotic Systems Technology and consists of a 486 33MHz PC with video LCD display and connections for interface outputs. Driving is via a motorbike handlebar control offering various functions such as steering, accelerator, braking and gear change. Control of the ploughing and fascine operations is done with the joystick.

Other functions have been modified to provide the 4-in-1 bucket controls. The bucket can be operated by joystick or by standard bulldozer lever type controls to provide such functions as raise/lower, digging/dumping, open/close and float/level grading.

The PC is able to offer many diagnostic capabilities - for our purposes items such as, gear status, vehicle speed, low oil pressure warning, safety status warnings, communication link dropout etc. have been incorporated.

Communications And Safety

Communications for remote links from the command vehicle to the remote vehicle offer control of the remote vehicle by two way radio link. The military vehicle radio, in the case of AVRE/CET is a VHF Clansman and was used to provide command functions, (e.g. engine start/stop, steering, accelerator and braking). Operation is at 4.8k baud rate and modulated into voice format. To prevent communication problems, two switchable antennas are used, one positioned 90degress out of phase with the other antenna. This method of control is suitable with military radio links such as the UK's next generation Bowman system.

The tele-link is only required in one direction from the remote vehicle to the command vehicle to be able to carry out the visual driving and manipulative tasks. We have used a 1.3GHz FM commercial microwave link (Gigawave Antennas

UK) with circular polarised antenna for all round performance. The main problem is, this method generally requires line of sight communication to transmit the high bandwidth video image. Alternatively fibre optic links that offer high bandwidth can be used but the trailing of cables over 1-2km can be a problem in some scenarios.

Safety is paramount when remotely controlling the vehicles. The computer hardware has a safety unit with watchdog/command data safety flags. An in vehicle safety cut-off switch is also incorporated. This feature is essential when conducting evaluation trials, some of which do take place at the researcher's site. Some vehicles lose their hydraulic breaking when the engine is switched-off, an important point to remember when considering safety. Software is required to be fail-safe but not safety critical.

Teleoperation Proving Trials

Trials were conducted in the UK to assess remote driving(1996) and engineer vehicle tasks (1997). Using colour monovision equipment, the MMI trials proved that driving was relatively easy but most other tasks varied in degrees of difficulty. Breaching ditches, grabbing and lifting was successfully achieved. With the 4-in-1 bucket, monovision highlighted perception problems during digging, such as loss of distance perception, depth and slope angle accuracy. The engineers became reasonably proficient within one day after using the equipment. Remote operations generally took up to 25% longer than when using the equipment manually.

ONGOING AND FUTURE WORK

Future topic to be covered are:

- Modelling for optimisation of operator perception and awareness, trials of stereo vision kit on the CET, assessment of head mounted displays and LCDs for stereo vision, use of inclinometers to judge slopes, the use of force feedback to "feel" driving and manipulation of the bucket, night driving - use of night vision equipment.
- Provision of increased user awareness, co-ordination with other nations and groups - US, France, SILVER (UK -DERA/Industry/Academia) and also keeping a watching brief on future potential technologies.

The core activity of our research for DDOR (Eng&NBC) continues to be improvements to in-service vehicles through current and future technologies such as VR. It is likely therefore that areas discussed in this workshop will feature in the future of remote control of Robotic Land Vehicles.

CONCLUDING NOTE

I believe that UGVs will become increasingly important for RLV tasks as they can be used on hazardous tasks without endangering men.

Reduced levels of manpower in the modern army need to be compensated for by increased levels of technology if the same or greater level of operational effectiveness is to be achieved. Repetitive and manpower-intensive tasks, such as convoying, logistic re-supply and security patrolling, could be carried out reliably by remote equipments and for longer periods, and would thus free people for other demanding tasks.

Bearing recent events from around the world in mind, it seems increasingly likely that the army of tomorrow will find itself involved more and more in operations other than war. Peacekeeping operations, with the intrinsic political unacceptability of loss of life, seem sure to promote the case for using teleoperated UGVs.

USING THE VIRTUAL REALITY MARKUP LANGUAGE (VRML) TO UNDERSTAND THE U.S. ARMY'S SIMULATION AND TRAINING DOMAIN

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Knowledge gained via the technology explosion continues to grow at an exponential rate. The size of all knowledge bases will become larger and more difficult to design. The Functional Description of the Battlespace (FDB) is the Army domain modeled for use in simulation development, Warfighter's Simulation 2000. The database that must be designed to describe everything that the Army does is going to be very large. Military unit descriptions, mission models, task process descriptions and other models reside within a large warehouse of data, models, algorithms, information and knowledge.

FDB users currently navigate on two-dimensional screens that use standard hypertext markup languages. In order to lead the FDB user in a more efficient and effective manner, a three-dimensional mapping and visualization of the FDB contents are sought. The gain will be increased understanding of the FDB knowledge warehouse. Using the virtual reality markup language (VRML), a virtual map and guide of the FDB will teach the abstract concepts inherent in complex domain modeling.

The FDB is becoming the Army's single source repository of validated, verified and accredited descriptions and performance parameters for all entities in the battle space. The data that populates the FDB spans the following categories and their interactions:

1. Human Characteristics: Performance data of behavior, capabilities and limitations, learning, thinking, situation awareness, judgment and the influences of doctrine, organizations and the physical environment. Mission models and task process descriptions are included in this category.

2. Systems and Materiel: Descriptions and performance data and utility data for individual and crew served battlespace systems as influenced by human operators, the natural and manmade physical environment, and impact of supply and maintenance operations. Equipment models show this type of information and data.

3. Physical Environment: Descriptions of natural and manmade physical and environmental conditions and effects including atmospheric, terrain, oceanographic, and space components for all climates world wide, including dynamic changes to the selected scenario battlespace that would occur due to natural environmental disasters (i.e. floods, earthquakes, sunspots, destruction of natural or manmade objects such as lakes, dams, etc.).

4. Organizations: Arrangements (templates) of systems into units following prescribed command structures to perform roles and execute mission objectives. This will represent the impact of cognitive processes of command and control, standard operating procedures (SOP), status of communication links with higher, adjacent and lower echelon units and the influences of outside activities on mission completion. Unit models contain this information.

Paper presented at the RTO HFM Workshop on "The Capability of Virtual Reality to Meet Military Requirements", held in Orlando, USA, 5-9 December 1997, and published in RTO MP-54.

TRANSFERRING VR TECHNOLOGY BETWEEN MILITARY AND NON-MILITARY APPLICATIONS

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ABSTRACT

Virtual Reality (VR) technology for commercial applications has been oversold to the public during the past 2 to 3 years. There have, however, been relatively few success stories outside of entertainment, but that does not mean VR cannot meet the requirements of non-military applications. It is important that we take a broader view of VR than helmet-mounted displays and wearable technology, one that includes interfaces able to display high fidelity 3D environments and models. In this paper I discuss the methodologies for accomplishing technology transfer. These include cooperative agreements, corporate funded R&D, and government funded initiatives. The requirements of commercial application domains, including industrial operations, government (non defense) operations, healthcare and entertainment are discussed and related to military training systems. Last I will propose ways that these two communities can work together on joint research and development, transferring technology bi-directionally, and the use of forums to enhance dialog and discussion. This paper is intended to stimulate a discussion of issues (such as intellectual property) which are appropriate agenda items for future joint discussions and workshops supported by both defense and non-defense VR developers.

INTRODUCTION

Virtual Reality (VR) captured the public's imagination and has been the darling of the technical communities that develop cutting edge computer interfaces and graphics computing capabilities. But like so many other promising technologies, it has been slow to mature sufficiently to be affordable, reliable, and to possess sufficient capability to meet the incited expectations. So now we hear plaints that VR is not really needed, that is too expensive, too slow, and too hard for its users to make a conceptual leap from what they see to the features of the real world a particular VR-based synthetic environments allegedly represented.

A different perspective is needed in order for VR to realize its potential. First, I propose we begin from an application perspective rather than, the more frequently taken, presentation viewpoint. Rather than being enamored with the "gee whiz" nature of VR, we need to see it as a feature of simulation technology, specifically user interface methodology. Furthermore, we should think of simulations as tools that aid their users in making decisions. These decisions can be for the purpose of learning, managing, or even of being entertained. But in any case the users have a certain goal in mind when they use a computer-based simulation. The user's interface to the simulation should be chosen or designed with a notion of that goal in mind.

Simulations are intended to be a model of some phenomena which exists in the world. Those phenomena could be some part or aspect of the world that is directly observable as well as one that is subatomic or even imaginary. In either case the use of VR as an interface mechanism exists solely to aid users in mapping the representation in computer simulation to their own conceptual understanding. With these perspectives in mind, let us consider how the needs for adequate VR technology to meet the needs of both military training and the commercial world complement one another and what we can do to collaboratively develop those capabilities.

METHODOLOGIES FOR ACCOMPLISHING TECHNOLOGY TRANSFER

Technology that has potential for dual use in both military and commercial settings has been long sought after. In the United States the federal government has tried mandating these efforts, encouraging government agencies to seek out opportunities to transfer their good ideas to commercial practice and even directly providing funding to accomplish technology transfer. While the notion has obvious appeal it has most often been unsuccessful because of the difficulty in

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stimulating a market for what are most often technologies for producing or defeating violence. Computer technology, especially better approaches to interfacing users to software, is a technology that can serve multiple purposes right from its development. We will examine some approaches to accomplishing dual use of VR technology.

Cooperative agreements between government development activities, such as laboratories or procurement commands, and non-defense activities, both commercial companies and university-sponsored research centers, should be considered as a way to reduce development costs. Cooperative agreements can be used to either leverage available funding or reduce costs of development by using the resources which a university research center offers. The difficulty with these agreements is insuring that property right issues are clearly addressed in the agreement itself so that future disputes over ownership and the rights to apply the results are clearly defined. I recommend that no one be permitted exclusive ownership of any cooperatively developed technology or product, rather those should be shared with full access to either party.

It might appear that corporate funded research and development will not achieve the goal of providing needed technology to the military. However, often contractors and companies, especially defense contractors, expend their limited R&D funds developing capabilities that do not meet the requirements of the military. Sometimes these capabilities have commercial application, but dual use technologies able to meet both defense requirements and find a niche in the marketplace are the ideal. The way for government activities to best leverage corporate R&D is to willingly define their requirements to industry. Dialog between government and commercial industry are important, there should be open exchange of information at the technology level. This does not mean that the possibility that something new, innovative, and revolutionary being developed by industry should be overlooked. There will always be innovations that will serve new purposes that are not yet defined. Government agents need to be alert to these, especially those that will improve defense training or combat capabilities enhancing combat effectiveness.

Last, there will always be a need for government funded research initiatives. Some government funding is needed to cultivate new technologies that will improve combat effectiveness because warriors can train better or operate more efficiently. Government scientists should not rely on their own laboratories to innovate all new technologies for their militaries. Defining what development needs to take place and sponsoring funding for it outside of government laboratories is still critical. A suitable strategy for meeting the technology needs of future military forces requires R&D organizations to adopt a strategy that includes all three types of approaches to leveraging capabilities outside of their own organizations. Cooperative efforts, dialog with industry on needs to guide corporate R&D investments, and government funded research should be components of such a strategy.

REQUIREMENTS FOR COMMERCIAL APPLICATIONS DOMAINS

I will discuss some of the basic requirements for VR interfaces to simulations in key non-military application areas. Keep in mind the perspective proposed in the introduction: that these simulations are tools that support decision-making and may benefit from the ability of VR technology to provide an immersive interface to that simulation. The areas for discussion are defined in four broad areas: industrial operations, government operations, healthcare, and entertainment.

Simulations to support industrial operations are not necessarily new, operations researchers, management scientists, and industrial engineers have used simulations to support their analyses for years. What is new is the opportunity to use simulations at a higher conceptual level to build and run on desktop platforms, enterprise level models. These simulations capture the emergent properties top-down for a given business enterprise. Today we can model entire factories, distribution systems, processing plants and etc., delivering those simulations to the manager's computer desktop for him or her to use for strategic planning and day to day operations. Given that these types of simulations will serve not just analysts but managers as well, we must consider when immersive technology adds to the ability of the non-technical user to relate what the computer presents to his or her understanding of the real world features being represented. VR technology will be of use if it is affordable and easy to use. Strap-on wearable equipment will probably not find favor with management level decision-makers. However, high resolution three dimensional presentations designed to aid understanding will find an eager market.

Local and state governments must meet an ever-increasing number of informed constituent groups. They are being held accountable for social programs, economic development and efficiency of public services. Simulations which, like those discussed above for industry managers, capture the overall characteristics of a government operation and which can be used to better plan for the future and manage day to day operations will be soon available to government officials. These simulations need an interface that not only helps decision makers, such as city managers and their staffs, do their jobs

better but are also suitable for explaining decisions to elected officials and the electorate. Planned investment in new infrastructures, such as schools, emergency services, or transportation, will be simulated to make the best choices and then demonstrated to the public. Three-dimensional high-resolution display technology as part of a simulation system based on GIS or other existing terrain databases will be in demand. These are the same features military trainers and operational planners want in their training or planning systems.

Healthcare needs simulations to help them more efficiently manage their operations and train medical personnel. Patient simulators are already under development. These full-size replicas of humans can train healthcare professionals in proper procedures for handling emergency medical situations. A VR system that permits personnel to practice similar procedures would also be widely accepted. This is a case where both the ability to display three dimensional images, but from a more limited image database than needed in the above domains, is important, and where the immersive capabilities of the system are important. The requirements for VR technology able to support similar medical training in both the commercial and military communities exists, but can serve other military training needs as well (e.g., dismounted warfare training). Also, managers of facilities and programs in healthcare will, in the near future, be seeking simulations to help them better manage their enterprises. Their requirements for VR technology will be similar to those of industrial and urban operations discussed above.

Entertainment has been viewed as a natural ally and collaborator in developing VR technology. The military training and entertainment communities have common interface capabilities per se, HMDs, interaction devices, and display screens. Collaborative efforts are therefore worth pursuing. One must understand though that entertainment requirements and the liberties taken in how they use the technology may impact the ability of what is developed to meet military requirements. Entertainment does not have to concern itself with fidelity to real world constraints (i.e., the laws of physics). It is more concerned with establishing a story telling context. Also entertainment can often afford to sacrifice scene fidelity for cost. Military training systems have to insure that whatever is delivered into the hands of warriors matches fidelity with tasks being trained. Sometimes the goals of entertainment and training are in opposition. I recommend that our best approach with entertainment is to let those organizations develop technology based on their profit incentives and determine, after it is completed, what capabilities it has to meet military requirements with or without modifications.

COLLABORATION BETWEEN DEFENSE AND COMMERCIAL APPLICATIONS

Given that there are common needs and opportunities to collaboratively develop technology between defense and some commercial areas I would like to discuss some ways to implement that collaboration.

Joint research and development involving government agencies and either academia or industry is probably the most difficult approach. It requires a clearly defined objective and plan. The agencies involved must agree early on what the project expects to accomplish. Each party involved should insure that those objectives will help them to meet their own organization's requirements when completed. This is key to embarking on a joint project, but more important to the overall success is a commonly agreed upon project plan with a specific schedule that includes milestones, planned reviews, and an agreed upon commitment of resources. R&D often has poorly defined end points and in many cases that is not necessarily bad, but in the case of joint efforts, better definition is required to insure the parties involved do not feel that the project failed them.

Frequently overlooked is the opportunity to transfer technology bi-directionally. Not only can government developed technology frequently be applied to meet commercial needs, but existing commercial technology is often able to meet military requirements with little or no modification. A model for accomplishing this is to establish partnerships between government agencies and other research centers that allow the research center access to government technology. This is usually accomplished through some sort of cooperative research agreement or memorandum of understanding. The partnership also should include a complementary contract vehicle that allows the government activity to procure honest broker services from the research center to help them evaluate commercial technology.

Information exchange between commercial and military sectors is probably the easiest way for these two communities to exchange useful ideas. Journals and conference proceedings that describe research are valuable. However, workshops and the actual conferences themselves are perhaps best. These types of forums allow researchers to dialog about what has been accomplished and understand best how to potentially apply it to meet their needs. They also allow ideas and requirements for future research to be exchanged.

SUMMARY

VR may not have met the public's expectations based on its hype as presented in the media but we, as a community, should not become discouraged. We must continue to work not just to improve display technology, a lot of which is being done by the OEM community to meet other needs (such as entertainment), but to work collaboratively with two purposes in mind. First we need to understand where common technical requirements exist that can help each meet our own requirements. Second we must be able to recognize and develop new capabilities in joint projects or by information exchange early in the R&D lifecycle. Only through joint and cooperative research and information sharing will VR technology move ahead and eventually meets the promises everyone holds for it. As a community we need to commit to working more closely together and enter into a dialog that addresses the issues involved in such collaboration.

HUMAN FACTORS ISSUES IN THE APPLICATION OF VIRTUAL REALITY TECHNOLOGY

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NOTES ON DAY 2 OF THE RSG28 WORKSHOP

INTRODUCTION

The subject of Day 2 of the December 1997 Workshop of the RSG 28 was Human Factors Issues. This subject formed a logical transition from Military Requirements of Day 1 and Assessment Methods and Military Applications of Day 3.

As an introduction to Day 2 the chairman suggested the following issues:

- Training & Information Systems
  - —Cyber Sickness
  - —Taxonomy of Proper Uses
  - —Measures of Performance / Effectiveness / Outcome
  - —Authoring / Design Tools
- Sense of Presence
  - —3D Audio
  - —Speech
  - —Haptics
  - —Olfactory
  - —Avatar
  - —Visual
  - —Locomotion
  - —Depth Perception
  - —Localization / Manipulation
  - —Temperature
  - —Humidity

As described below, the speakers covered many of these issues in their discussions, how VR was applied, which human factors were involved, what evaluation results they obtained and what future plans they had. Also, assessment methods were presented: what was being assessed and how, strength and weaknesses and potential uses.

PROGRAM

Mr. S. Grant	(CA)	Navigation In Virtual Environments
Dr. J. Templeman	(US)	Performance Based Design of a new Virtual Locomotion Control
Dr. R. Fischer	(US)	Methods for Improving Depth Perception in HMDs
Dr. R. Kennedy	(US)	Capability of Virtual Environments to Meet Military Requirements
Dr. P. DiZio	(US)	Side Effects and Aftereffects of Immersive Virtual Environments Created with Wide Field of View, Helmet-Mounted Visual Displays
Dr. N. Beagley	(UK)	Human Body Modeling as a Human Factors Engineering Tool
Dr. R. Carrier	(FR)	VirtualMan: Fully Articulated Man Model
Dr. P. Werkhoven	(NL)	How Real Are Virtual Environments?
Dr. B. Knerr	(US)	Interface Issues in the Use of Virtual Environments for Dismounted Soldier Training
Mr. S. Davidson	(US)	Development of a Virtual Environment Software Testbed using COTS Software Components

In particular, the speakers addressed the following in detail.

Grant
Navigation, locomotion, and depth perception in VE

- Users are greatly disoriented in VEs
- Walking interface produces better transfer of training than joystick (shorter distance but not time)
- No difference in simulator sickness between two interfaces
- Navigation benefits from internal cues
- Non-visual information well-suited to navigation in areas that appear different from training (smoke, lack of visual data, traveling out of sight of rehearsed areas)

Templemen
Features of Gaiter

- Can preserve metrics between physical & virtual space

Example: Map knee extension into virtual displacement

- Virtual motion occurs as the knees rock back and forth

Do not have to wait for the gesture to be completed

- Gesture-less Gesturing

No special vocabulary to separate forward, side, & back steps

- Equipment is compact & relatively inexpensive

Wireless version can be built today, at greater expense

Fischer

- Simulation using HMDs has a lot to offer

Size, weight, cost, portability

- Problems are associated with scene immersion, resolution, and depth perception
- Adding cues of variable convergence and accommodation in synchronism with eye fixation point will help significantly as will blurring of far background
- Efforts will lead to viable implementation of these techniques

Kennedy
Cybersickness in VE

•VR systems which convey feelings of presence can produce reports of symptoms similar to those of motion and simulator sickness

•Exposure to VR symptoms can also produce aftereffects such as postural imbalance and aiming biases

•The former problems can influence users to not use the system but the latter can have safety implications

•Preliminary findings from 3 VE systems show weak or zero correlation between the subjective and objective measures of aftereffects which implies both types of disturbances need to be measured in evaluation of VE systems

•The fact that sickness severity does not appear to be correlated with either of the objective measures of exposure aftereffects such as past pointing and ataxia may suggest different neural pathways may be involved in these two types of aftereffects

Dizio

- Motion sickness and postural instability are serious side effects and aftereffects of a 15 min session with a wide FOV HMVD
- Individual susceptibility is very stable
- Aftereffects involve sensitization:
  - symptoms which appear to be gone in a resting subject reappear in full force - - with minimal exposure to real or virtual motion
- Delays in visual update contingent on head tracking, FOV and resolution are etiological factors
- Visual update delay is a factor specific to HMVDs
- No external visual or real motion is necessary
- Voluntary head movements are provocative
- Visual update delay somewhere between 20 and 40 ms is the threshold for eliciting motion sickness during a 15 minute exposure, for wide FOV HMVDs

- Establishes a target for system specs
- Provides the rationale for developing incremental exposure routines to prevent side effects

Beagley
Body Modeling for VE: addressed the following commercial models

- Andriod: Mechanical Dynamics
- COMBIMAN: CERIAC
- Crew Chief: CERIAC
- ERGO: Deneb
- JACK: Transom
- Kinemation: Alias Wavefront
- MannequinPRO: HumanCAD
- MDHMS: Boeing
- Poser: Fractal Design
- Safeworks: Genicom
- Sammie: British Technology Group

Carrier
Discussed the following issues regarding modeling

- Definition of grid and key postures
- 3D Scans
- Extraction of digitized data from raw data
- Man model definition
- Layout of digitized data onto man model
- Validation

Werkhoven

Localization of objects in VE

- Spatial perception in VE is not yet as good as in the real world
- Virtual hand control is promising:
  - fast and accurate
  - likely transfer of acquired visual-motor skills
- Design tasks: discrepancies because of
  - too coarse modeling
  - inaccurate tracking
  - lack of force feedback

Knerr

- VE Performance is worse than Real World performance on a variety of visual tasks
  - Contributing factors are likely to be FOV and resolution
  - Distances in VE are underestimated
  - Stereoscopic displays improve performance only at short distances
  - Head coupling sometimes improves performance
  - Image fidelity may be a consideration for transfer
- Locomotion simulators can affect the perception of distance in VE, but not always in the ways we would have predicted
- Compensatory cues can affect distance perception in VE
- What constitutes a "good" locomotion simulator is likely to be task dependent

Davidson

Lessons Learned from testbed development

- Prototyping => VE Authoring Language
  - Describes behaviors, object attributes
  - Event driven/programmable
- Integrated dB Manager/Multi-process harness
  - Performance, performance, performance
  - Open architecture => 3rd party attributes/processes
- Portability
  - Binary object database / ASCII authoring language

CHAIRMAN'S FINAL SUMMARY

Upon conclusion of the speakers and the discussion of their papers, the chairman concluded the day by leading a discussion of the need for a technology roadmap. This would promote not only collaboration among research personnel, but also demonstrate to our respective nations' budgeting authority that significant technical progress is being made without unnecessary duplication of effort. A prototype roadmap containing technical issues, technical interchange points, and a time scale was presented and discussed.

NAVIGATION IN A VIRTUAL ENVIRONMENT USING A WALKING INTERFACE

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For years, aircraft crews and armored fighting vehicle crews have benefited from training in the benign, controlled, and instrumented situations created by simulation. Virtual reality (VR) technologies are now starting to bring these benefits to the training of dismounted soldiers.

Simulation for dismounted combatants has numerous applications. In current combined arms simulations, only constructive infantry, controlled from a workstation, are available. Their lack of sophistication, relative to their human counterparts, is thought to detract from the validity of the combined arms simulation. Adding virtual infantry would increase the benefit to all participants. Reconnaissance forces and special operations units could plan and rehearse missions using simulation. The ability to explore a future area of operations, such as an airport where hostages are being held, from a first person perspective would allow forces to assess and rehearse lines of fire, escape routes, and fields of view. Similarly, personnel who must enter toxic environments, such as ship's damage control parties and nuclear power station maintenance crews could rehearse different scenarios ahead of time and familiarize themselves with locations they have never visited.

A HUMAN FACTORS PROBLEM: NAVIGATION

A human factors problem threatens to prevent dismounted combatants from obtaining the full benefits of simulation. People are prone to becoming lost in virtual environments (VEs) (Durlach & Mavor, 1995; Psotka, 1995). This is obviously a problem, for being lost impairs performance in the virtual environment and it means that there is little spatial knowledge being gained for transfer to the real world.

Conventional movement interfaces for VR, such as joysticks and 3D mice, likely contribute to disorientation because they do not provide the vestibular and kinesthetic feedback people use to navigate in the real world (Loomis, Da Silva, Fujita, & Fukusima, 1993; Mittelstaedt & Glasauer, 1991; Schmuckler, 1995). Thus, only visual information is available for navigation by dead reckoning (Gallistel, 1990), and that source of information is constrained by the limited vection produced by the narrow fields of view obtained in most VR displays. Seeking to address this problem, Iwata and Matsuda (1992) provided users with special roller skates to move through a VE. The effect of their interface on users' distance perception in a VE relative to a point-and-fly interface was equivocal, however. Slater, Usoh, and Steed (1995) used the presence of foot motion to move users in a VE and found positive effects on feelings of immersion, but they did not measure navigation effects.

AN EXPERIMENT

This experiment examined the role of proprioception in the navigation of VEs by letting subjects explore a computer model of a large, complex building, the Ontario Science Centre (OSC), using either a walking interface or a joystick. If proprioception facilitates navigation in VEs, subjects using the walking interface should be better oriented in the VE and acquire more knowledge of the OSC for transfer to the real world. To aid the interpretation of the results, the experiment included control groups that either studied a map of the OSC, walked through the real OSC, or received no information about the OSC.

The VE

The OSC is an excellent place to study navigation because it has an unconventional floor plan and contains many unusual items, thus providing unique and memorable locations while preventing subjects from finding their way using heuristics derived from their experience with more common buildings. For this experiment a model of 7,200 square meters of the

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OSC, including hundreds of exhibits, was constructed using shaded polygons. Eight of the exhibits were selected as destinations for the navigation task according to their location in the OSC, their size, and their distinctive appearance.

The Walking Interface

The walking interface was a platform 1.22 m in diameter surrounded by a hand rail. The surface of the platform was covered with a slippery laminate that allowed subjects to easily slide their feet across the surface.

Subjects wore a magnetic sensor on each foot. By walking in place, the subject's foot motion moved the subject's eye point in the VE. Horizontal foot movement, either forward or backward along the subject's body direction produced forward movement in the VE. This is similar to normal walking, where the head moves steadily forward as the feet move back and forth beneath the body. The farther and faster the subject moved his feet on the platform, the farther and faster he moved in the VE. On the basis of a pilot experiment, the magnitude of the foot movement was amplified to produce a subjective match between walking speed and visual flow.

Design of the experiment

Eighty subjects, all older than 15, completed the experiment. The nature of recruiting resulted in a different ratio of men to women in each experimental condition, but because inclusion of gender as a covariate in the analyses reported below did not change any of the results, the effects of gender will not be reported.

Five groups of 16 subjects took part in the experiment. The VR-walking group explored the computer model of the OSC using the walking interface. The joystick group did the same using a joystick. The map group explored the OSC using a floor plan that contained representations of all exhibits, and by looking at photographs of the destination exhibits. The real-walking group explored the real OSC. The no-experience group received no information about the spatial arrangement of the OSC, but they did see photographs of the destination exhibits.

In the first phase of the experiment, subjects in the VR-walking, joystick, and map groups completed a simulator sickness assessment. The assessment consisted of a 28 item questionnaire (the Simulator Sickness Questionnaire, the SSQ; see Kennedy, Lane, Berbaum, & Lilienthal, 1993) and an eyes-open Romberg balance test, performed on a force platform.

In the training phase, the experimenter guided all subjects, except the no-experience subjects, through one circuit of the OSC, visiting the eight destinations. The VR-walking and joystick groups did this by moving through the computer model. The map group was directed along a path on the map, viewing photographs of each destination as they reached it on their map. The real-walking group followed the tour in the real OSC, and the no experience group only viewed the photographs of the destinations. At the start of the tour the experimenter told the subjects that they would be asked to find the destinations later in the experiment, and that they should attempt to learn the location of the destinations.

To determine how well the subjects were oriented in the VE, each time the VR-walking and joystick groups reached a destination during the training phase, they were asked to face back to the origin of their VR tour. If they were disoriented, they should make large errors, but if they were not, their errors should be small. To provide a performance benchmark, the real-walking subjects performed this same task while walking in the real OSC.
Upon completing the training phase the VR subjects and the map subjects again completed the simulator sickness test.

In the transfer phase, the subjects attempted to find the shortest path to the eight destinations in the real OSC. The experimenter named a destination and the subject sought only that destination until it was found. The subjects were asked to find the destinations in an order that differed from the order in which they saw them in the training phase. This was done to force the subjects to find new routes and truly navigate rather than just recall the path followed during training. The time and distance taken to find the destinations were recorded.

Results

In the orientation task, the mean absolute angular error from the attempts to point back to the origin of the tour ($\pm$ 1.96 standard error of the mean) were 33° (±14°), 71° (±14°), and 66° (±8°) degrees for the walking, VR-walking, and joystick groups, respectively. An ANOVA showed that there was a difference amongst the groups, $F(2,39) = 13.11$, $p <$

.01. Planned comparisons indicated that the two VR groups performed worse than the real-walking group $F(1,39) = 26.21, p <.01$, but they did not differ from each other, $F(1,39) < 1$.

The mean distances required by each group to find the destinations are presented in Table 1. There are significant differences amongst the means, $F(4,75) = 5.71, p < .01$. In particular, the VR-walking group followed a shorter path than the joystick group, $F(1, 75) = 3.99, p < .05$. The VR-walking group was also superior to the no-experience group, $F(1,75) = 7.16, p < .01$, but the joystick group was not, $F(1,75) < 1$. The route taken by the joystick group was farther than that taken by the real-walking group, $F(1,75) = 12.94, p < .01$, but the difference between the VR-walking group and the real-walking group was not significant, $F(1, 75) = 2.83, .10 > p > .05$. Similarly, the map condition did not differ significantly from the joystick group, $F(1, 75) = 1.42, p > .10$, or the VR-walking group, $F(1, 75) <1$.

	Real Walking	VR-walking	Joystick	Map	No Experience
Mean Distance (m)	643	753	886	805	928
Mean Time (s)	599	805	938	909	969

Table 1. Performance in the Transfer Phase

The mean times to find the destinations are reported for each group in Table 1. Following a square root transformation of the time data to alleviate heterogeneity of variance, an ANOVA revealed differences amongst groups, $F(4,75) = 5.91, p < .01$. Planned comparisons indicated that the VR-walking group required less time than the no-experience group, $F(1,75) = 3.15, p < .05$, but the joystick group did not, $F(1,75) <1$. Both the VR-walking and joystick groups took more time than the real-walking group, $F(1,75) = 6.77, p < .05$ and $F(1,75) = 14.71, p < .01$, respectively. The differences between the map group and each VR group were not significant, both $F(1, 75) <1$. Finally, the VR-walking group did not differ from the joystick group, $F(1, 75) = 1.78, p > .10$.

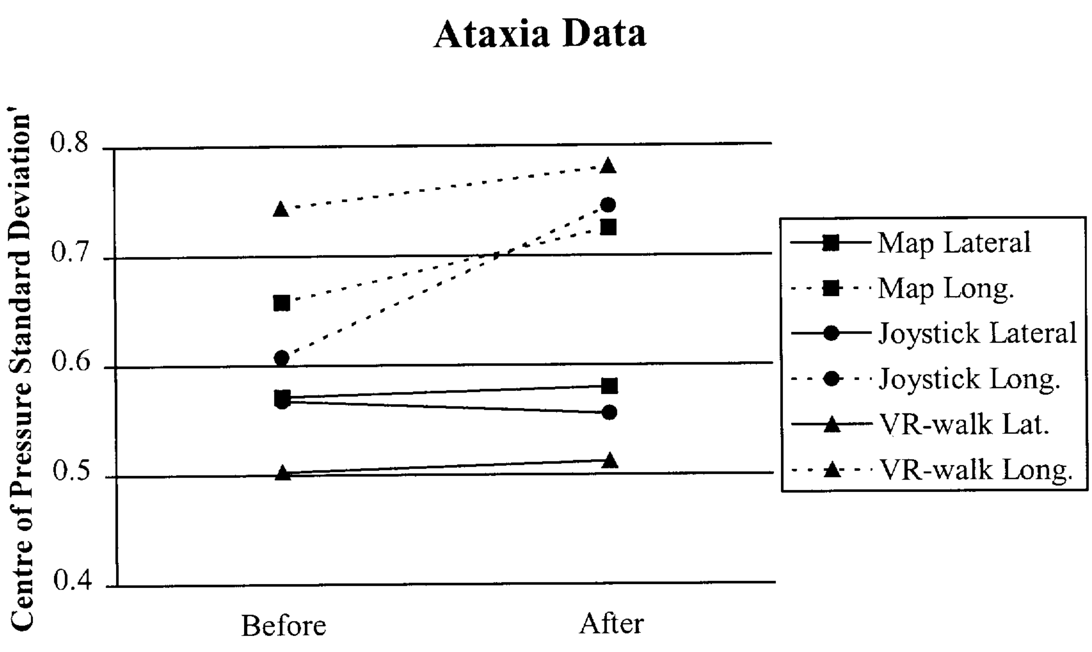

Figure 1.

The data from the balance test, presented in Figure 1, revealed no effect of the VR training. The changes in lateral and longitudinal instability experienced by the VR groups were no greater than those experienced by the map group, all p > .1.

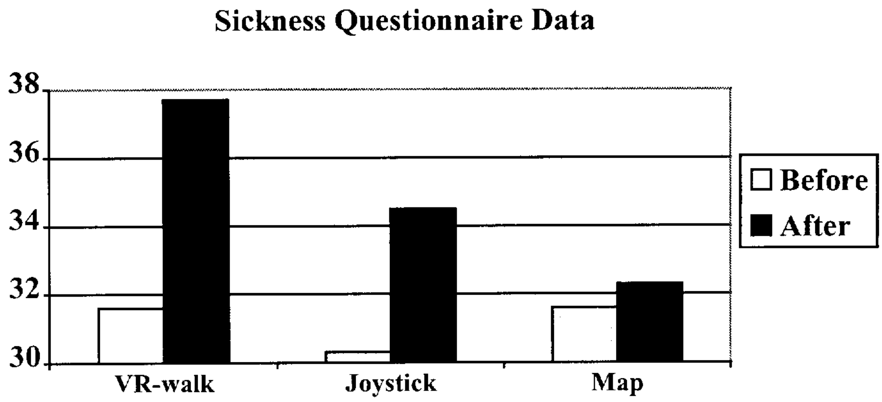

Figure 2.

The sickness questionnaire data in Figure 2 show that the increase in symptoms following training was significantly greater for the VR groups than the map group. Using conversion equations provided by Knerr (1997), SSQ scores were derived from the **questionnaire** data and are presented in Figure 3

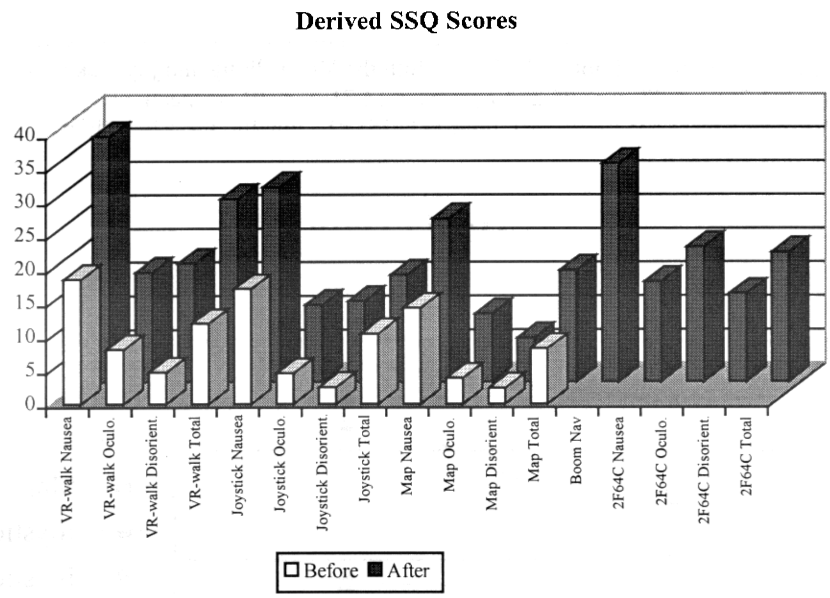

Figure 3.

along with scores from another VR system, (Witmer, Bailey, & Knerr, 1996) and the worst of 10 surveyed flight simulators (Kennedy, Lane, Berbaum, & Lilienthal, 1993).

CONCLUSIONS

This experiment documented that people can become quite disoriented in VEs and that the best way to learn about a space is to visit that space. However, VR proved itself to be an effective alternative to training in the real location. Spatial knowledge acquired in a VE can assist performance in the real world, but success is not assured. Navigation in VEs remains a human factors problem.

A walking interface to VR is helpful. It does not appear to help subjects remain oriented in the VE, but people transfer more knowledge to the real world if they use the walking interface rather than a joystick (at least in terms of finding the shortest path to a destination).

The VR system used here caused simulator sickness, but the levels were not severe. They were comparable to other VR systems and some flight simulators. In terms of SSQ scores, this system seems to appear particularly nauseagenic, but there is reason to argue against this conclusion. This experiment was conducted during the winter, when many subjects were carrying thick coats. This may have caused higher responses to the sweating item in the nausea scale. Indeed, of the items used to derive the nausea score, the sweating item had the highest mean.

Walking interfaces to VR appear to have significant military value. Users demonstrate better navigation performance if they use a walking interface rather than a joystick. This is important, not just for its own sake, but also because it indicates that users may be able to obtain non-visual information for navigation using the walking interface. Thus, they might be able to navigate when visual information is scarce due to smoke, night, lack of data for construction of a visual database, or when landmarks are destroyed. Furthermore, not being dependent on landmarks for navigation allows for improvising new routes out of sight of known landmarks.

The walking interfaces available for obtaining these benefits can be compared on four dimensions pending further results on the role of proprioception in navigation. Ideally the interface will be inexpensive, simple, unobtrusive, and allow the user to physically turn in any direction. A conventional treadmill has several advantages. It is inexpensive, simple, and permits a normal gait, free from wires. However, it only supports movement in one direction. The omni-directional treadmill allows walking in any direction with a normal gait, free from wires, but it is expensive and complex. The rollerskate system developed by Iwata and Matsuda (1992) is simple, affordable, and allows movement in any direction, but it encumbers the user with wires and a harness. Slater, et al. (1995) developed a simple and inexpensive omni-directional interface, but it uses wired sensors that simply moves the subject at a pre-set speed. The feedback from walking naturally is not available. For this experiment a walking interface was developed that was low-cost, simple, and omnidirectional, but it does not allow a completely natural gait, and the user must wear wired sensors on each foot.

Ultimately, a better understanding of human navigation is required to field an optimal walking interface. The kinesthetic and the vestibular systems are both involved, but their relative contributions are not known. Also unknown is the type of information derived from each system. Both can sense angular and linear movement. Once the nature of the information is known, and how important it is, new hardware can be targeted to provide only the information necessary, freeing the user from the costs and constraints entailed in providing the unnecessary information.

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PERFORMANCE BASED DESIGN OF A NEW VIRTUAL LOCOMOTION CONTROL

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ABSTRACT

The ability to simulate walking around in the environment is a key element missing from most of today's joint forces simulations. A number of sensor-based techniques are widely used to maneuver through Virtual Environments but they introduce artifacts into the interaction. Mechanical motion platforms have also been applied to surmount these difficulties, but they tend to exhibit different but equally troublesome side effects of their own. This paper examines the interrelationships between virtual motion control and other critical actions soldiers need to perform in VE. The goal is to allow the user to maneuver through VE in as similar a manner as possible to walking through the real world. If the interactions between different controls and sensory feedback can be made comparable to the interaction between actions in the real world, then there is hope for constructing an effective new technique. Human performance requirements are viewed from an analytical standpoint: pointing out the interactions between a full set of virtual controls that would allow the user to act, sense, and react to their environment. Candidate solutions are discussed as the analysis is developed. This has lead us to a promising new design for sensor-based virtual locomotion called Gaiter, introduced in this paper.

THE TECHNOLOGY AND ITS USE

Virtual locomotion is a control technique for allowing a person to move naturally over long distances in the Virtual Environment (VE), while remaining within a relatively small physical space. Ideally such an interaction technique will allow users to perform the same coordinated actions and move with the same agility in VE as they do in the real world. Virtual locomotion is essential for constructing Individual Combatant Simulators where the soldier interacts directly with the surrounding environment. Previous military simulators have focused on vehicular weapons platforms where motion was controlled through the same kinds of control devices that are used to pilot the actual vehicle. Either actual or reduced cost versions of the controls used to pilot aircraft or drive a tank can be used in flight and tank simulators. This made it relatively straightforward to attain a high level of realistic interaction. For a locomotion simulator, the user's physical body is the control device and the user's avatar (representation of the user's body in VE) is the "vehicle" being controlled. This changes things considerably, calling for new kinds of control actions.

DoD needs individual combatant simulators for both training and analysis. Such simulators can be used to train soldiers in team operations and tactical doctrine. They can be used to familiarize a group with a specific environment, and to plan and rehearse operations in that environment. An accurate VE model of an embassy could be used to train a team to carry out an embassy evacuation. For analysis, it is important to adequately simulate the performance of individual combatants in combined force simulations to make the simulation more complete and enhance its validity. The individual combatant is the "missing element" in today's military simulators. When this element becomes available, combined force simulations can be used to analyze and evaluate new tactics and operational plans. It will also allow new technology (for foot-soldiers, or jeopardized by foot-soldiers) to be studied with a comprehensive simulation.

HUMAN FACTORS ISSUES INVOLVED

A Framework For Analysis

The goal is to find a virtual locomotion control technique as similar to actual locomotion as possible. But exactly how should it be similar? We approach this question through a careful analysis of the interrelationship between natural and control actions.

Specifying A Control Technique

It is useful to divide a control technique into two parts: the *control action* made by the user and the *controlled effect* produced by the computer system. Since in this case the control technique is used to mimic an action performed in the

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real world, there is a corresponding *natural action* and *natural effect*. For virtual locomotion the natural action is perambulation (walking, running, sidestepping, etc.), the natural effect is real motion (physical displacement), and the controlled effect is virtual motion. There are many alternative control actions that can be used for virtual locomotion. They will be considered in terms of the analytical framework developed in this section.

Interaction With Other Natural Actions

Natural locomotion interacts with a wide variety of other actions. These actions include looking (directing both the head and eyes), manipulation (typically involving the hands, as in pointing a rifle), posturing (moving parts of the body, for purposes other than looking, manipulation, or locomotion), and thinking. Thinking is included because it is something the user does which interacts with other actions, including locomotion. Often the expression "cognitive load" is used to describe how thinking can limit or be limited by the performance of other actions.

Components Of Locomotion

Locomotion control will be divided into two components: control over the direction of motion (steering) and the rate of motion (speed). Steering may include a facility for sidestepping (i.e., moving in a direction other than where the torso is oriented).

Simulating A Natural Capability

The goal of simulated locomotion is to provide a control to maneuver through VEs as naturally as possible. We now have the terms to state this requirement a little more formally. (1) The control action should be similar to the natural action with respect to their intrinsic properties (constraints on movements, caloric energy expenditure, etc.). (2) The control action should interact with other actions (looking, manipulation, posturing, and thinking) in a similar manner to the way the natural locomotion interacts with other actions (e.g., freeing the hands for manipulation and allowing a normal level of coordinated head, arm, and leg movements). (3) The components of the control action (steering and speed control) should interact with each other as the components of the natural locomotion interact. (4) The controlled effect should be similar to the natural effect (i.e., the rate and precision of movement should match). This is clearly a tall order for any virtual locomotion control to meet, but it provides a basic set of criteria which can and should be applied to all candidate techniques.

Compatibility With Turning The Body

A great deal of compatibility with other natural actions can be achieved by having the user turn in VE by physically turning the body. This allows actions like turning the head, pointing the hand, or wielding a weapon to be performed as a natural coordinated motion. It also allows the reflexive orientation a person might have towards or away from a stimulus to be used effectively (e.g., turning one's head to view the source of an unexpected sound). Another advantage of using the natural action of turning is to avoid a potential sensory conflict. People sense turning through their visual, aural, haptic, and vestibular systems. They build up a sense of their orientation in an environment through the temporal integration of this information. Peoples' vestibular sense of motion contributes to their ability to navigate through virtual environments.

We therefore prefer to treat turning the body as an action separate from locomotion, limiting locomotion to the control of the translational motion of the body through space. Steering is still required to control the direction of this motion. Although this eliminates the need for the control action to encompass turning, it imposes the constraint of having the control action be compatible with physical turning. The user should be able to perform virtual locomotion while turning, and the path traversed should vary accordingly.

The body can be turned in several different ways. Most of the time, people step to turn: by lifting and planting their feet in a different direction on each successive step, the body turns to face a new direction. People also pivot on their feet to turn. Here the foot is turned while it continues to support a person's weight. There are one- and two-footed pivots. Pivoting provides an means of turning the body that is more economical in terms of both time and space than stepping to turn, particularly critical in martial situations.

Compatibility With Real Motion

It is highly desirable for the virtual locomotion control to be compatible with other sorts of postural movements like bending at the waist or crouching down. These may be thought of as special purpose actions - essential for certain tasks. A user might bend to look around a corner, or crouch to hide behind an embankment. It would be desirable if those motions could be made in a natural manner while performing virtual locomotion. We do not want users to learn an entirely new vocabulary of control actions just to allow them to move in different postures.

It is also desirable to allow virtual locomotion to be intermixed with natural locomotion. The user could move forward in VE by making control actions or by taking actual steps (albeit over a limited range). Physical movements work well in VE, but must remain within tracker range and within the available space.

Candidate Control Actions

A variety of control actions can be performed to steer and set the speed of motion through the VE. This section will describe sensor based controls that have been employed for this purpose. The most obvious and widely used steering technique is that of pointing. With a vehicular control, the user's body remains fixed in the vehicle and a rate dependent pointing device, like a steering wheel, is used to turn the vehicle. In an individual combatant simulator, the user can turn the body, so pointing can be direct.

Steering Controls

Head-based steering is probably the most widely used steering control for VE systems. It is economical because the same position tracker used to determine the user's field-of-view is used to control the direction of motion. Other advantages of head-based steering are that it "encourages" the user to look where s/he is going, and the hands are free for manipulation. The disadvantage is that looking and moving are no longer independent. The user cannot turn the head to look to the side while moving without altering the path. Bowman demonstrated this problem by asking users to walk to a position pointed at by an arrow in VE [Bowman, Koller, & Hodges, 1997]. Users had to keep turning to look at the arrow as they moved toward the desired position; the act of looking interfered with their motion. The task was much easier to perform using hand-based steering.

Hand-based steering techniques determine direction either from where the arm is pointed, where a hand-grip is pointed, or where a finger is pointed when an instrumented data-glove is worn. Hand-based steering frees the head for looking and allows the user to move sideways relative to the head or body. The disadvantage is that the control interferes with manipulation. The hand is occupied so that using the hand for other tasks leads to conflicts and interruptions. The user also must remain aware of the significance of where the hand is pointed.

Torso-based steering frees the head for looking and the hands for manipulation, but it does not support sidestepping. Often people move in the direction where the front of their torso is pointing, but sometimes they do not. A soldier aiming a rifle across his chest may prefer to advance in the direction he is aiming.
There are three approaches to lean-based steering: tilting the upper torso (bowing), shifting weight relative to one's feet, and shifting one's weight relative to a platform. All three kinds of leaning provide hands-free operation and can support sidestepping. Fairchild, Lee, Loo, Ng, and Serra, [1993] implemented a system based on shifting the user's head position by tilting the upper torso (bowing). This control is incompatible with the user tilting the torso for other purposes. The second approach, shifting weight relative to the feet (i.e., to the basis of support) is of limited use because the continuity is broken when a user steps to turn.

The third type of lean-based control is shifting one's weight relative to a platform. Max Wells at the University of Washington's HIT Lab has developed such a system [Wells, Peterson, and Aten, 1996]. Motion is controlled by moving one's body locally, relative to a central neutral position. When immersed wearing a head-mounted display, the user might lose track of where s/he stands with respect to the neutral position. The direction and rate of optical flow provides one indication of where the user is situated. A set of elastic straps attached to a ring around the user's waist gives haptic feedback, pushing the user back towards the neutral position. The directional coordinate frame is relative to a fixed external point in space, an unnatural condition that produces interesting side effects. This makes turning the body and controlling the direction of motion even more independent than they are with natural locomotion. The user may choose to move in one direction and then turn to face in another, making it as easy to "run" backwards as forward. This approach is incompatible with physical locomotion because velocity is controlled by relative position of the body.

Speed Controls

Speed can be controlled using finger pressure, by the degree of leaning (when leaning is used for steering), by the rate at which the user steps in-place, or by the degree of leg movement when the user steps in-place. Only the use of finger pressure will be discussed in this section. Often a pair of binary switches attached to a hand control are used to invoke either forward or backward virtual motion. This is a widely used technique, easy and inexpensive to implement. We have tried using pressure sensitive buttons and recommend their use because it provides a smooth way of varying speed. A major advantage of hand controls is that they work independently of head, torso, and leg movement and are thus compatible with a wide range of physical motions. The primary drawback of using the hand to control speed is that it interferes with using the fingers for manipulative tasks. As VEs become richer and engage the user in more complex tasks, they require a greater commitment of the user's hands for manipulation. This is most evident for combat systems where the user needs to hold and aim a weapon both at rest and in motion. A second drawback of using hand controls with head-mounted displays is that the user cannot directly see how his hand holds the grip or how fingers touch the buttons. This limits the number of buttons the user can deal with.

REVIEW OF THE STATE-OF-THE-ART

This review will cover both mechanical motion platforms and a promising new sensor-based virtual locomotion system.

Mechanical Locomotion Systems

Uni-directional Systems

A number of mechanical solutions have been proposed. One class of device is the uni-directional systems that limit movement to one direction and require a special control action for turning the virtual world around the user. An early system is the treadmill used at University of North Carolina in their Architectural Walkthrough System [Brooks, Airey, Alspaugh, Bell, Brown, Nimscheck, Rheingans, Rohlf, Smith, Turner, Varshney, Wang, Wber, & Yuan, 1992]. It uses a handle in front that the user twists to steer. They report that the treadmill is disorienting, probably because there is no true sense of turning which is helpful for route learning. Spinning the virtual world about the user produces an odd transient effect. Other uni-direction systems possibly suffer from the same disadvantage. Sarcos Research Corporation developed the TREADPORT, a large treadmill that allows the user to stand, kneel, sit, and lay prone [Youngblut, 1996]. The user is tethered for safety. OSIRIS, developed by the US Army's Night Vision Laboratory, is a stair-stepper device that can only be used upright [Lorenzo *et al.*, 1995]. It can present forward motion only; a hand control is used for steering. The Individual Soldier Mobility Simulator (ISMS) was developed by Sarcos Research Corporation in conjunction with the Army Research Institute. The user stands on two robotic arm boot plates that create the sense of walking or running over different terrain, and ascending or descending stairs [Lorenzo *et al.*, 1995].

Multi-directional Systems

Other mechanical systems allow the user to move in multiple directions. Sarcos Research Corporation's Uniport is based on a unicycle [Lorenzo, Poole, Deaso, Lu, Kekesi, Cha, Slayton, Williams, Moulton, Kaste, MacKrell, Paddison, Rieks, Roth, & Wodoslawsky, 1995]. The user remains in a seated position and turns around a pivot point by applying torque to the seat. This engages a motor to turn the seat at a controlled rate. (This system is at the borderline between a vehicular and locomotion control.) The user's hands are free to hold a gun or other objects.
The Virtual Perambulator [Iwata and Fujii, 1996] uses a sliding motion of the feet to indicate walking. The user wears sandals with low friction film on the middle of the sole and a rubber brake pad at the toe. The user glides on a low friction surface by pushing the waist against a hoop that surrounds the user and sliding the feet. A position sensor attached to each ankle and contact sensors on the bottom of each foot allows the system to recognize the length and direction of each step to specify the movement in VE. An earlier version used roller skates instead of the low friction film. The placement of the hoop at waist level does not allow a user to hold an object by the side.

The Omni-Directional Treadmill (ODT) developed by David Carmein of Virtual Space Devices Inc. [Darken, Cockayne, & Carmein 1997] allows the user to walk in any direction. The mechanism consists of a pair of conveyor belts nested one inside the other. Each track moves horizontally and the tracks are oriented perpendicularly to each other. The outer track has rollers on it so that it can transmit the motion produced by the inner track. The rollers can thus convey motion in any direction to the user's feet resting upon it. The active surface of the motion platform measures 50"x 50". A control system is used that seeks to keep the user centered in the middle of the platform. The system is very effective at

allowing a user to walk in a straight line in any direction. People have little difficulty accelerating along a straight path. Turning while accelerating can lead to a misalignment between the user's direction of translation and the centering motion of the mechanism. This is apt to make the user lose his/her balance and stumble. Even turning in-place can be difficult because the tracking system registers the motion and compensates for it by moving the surface under the user's feet. Sometimes the dynamics of natural locomotion go beyond what the ODT can support. People can decelerate very quickly, coming to a full stop in a single step, and if they pivot while walking fast they can redirect their motion even more rapidly. Further, people perceive linear and angular acceleration using their vestibular system. A user immersed in VE, standing on a "perfect" motion platform would have the sensation that the vestibular perception of linear acceleration were "turned off". This alone will make it difficult to perform certain actions, even if the dynamic response of a motion platform were perfect.

First Attempt Using Walking-In-Place

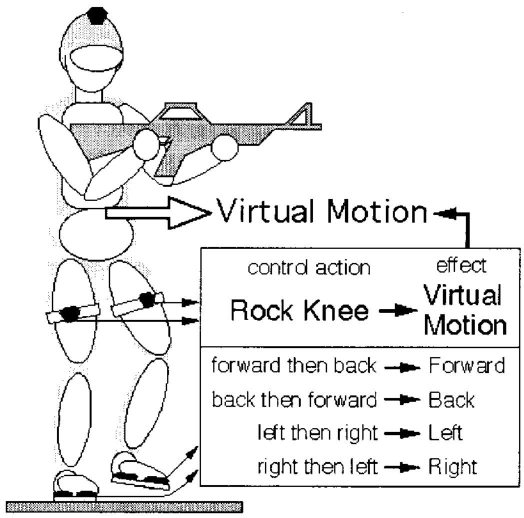
The first virtual locomotion system we implemented and tested used a combination of torso-based steering and step-based speed control. Sidestepping was not supported. A position tracker was attached to the user's waist and pressure sensors were mounted under the ball and heel of each foot on the insoles of their shoes. The basic idea was to initiate virtual motion when the user took an in-place step and use the rate of stepping to control speed. The system also had to be able to distinguish between stepping to turn and stepping in-place to initiate virtual motion. We made the mistake of putting the burden of making this distinction on the user. Forward and backward virtual motion were indicated by pushing off the ball or heel of the foot, respectively. Flat footed steps produced no virtual displacement and were to be used for stepping to turn. The user could also turn while advancing in VE by pushing off the ball of their foot while stepping to turn in-place. This was easy to do when the user concentrated on it, and the computer had no problem recognizing these distinctions. But users tend to get a little "sloppy" when they started thinking about something other than how they stepped. Although ninety percent of their steps indicated their intention, the remainder is enough to spoil the technique. Unintentionally movement, or missing a step is quite disconcerting.

Gaiter: Our New Locomotion Control

We developed a second generation locomotion control to allow the user to more naturally control their movements (without having to concentrate on their footsteps) and to support sidestepping. We call the new system *Gaiter.* Its design is based on generalized classification of human gait that encompasses sidestepping and in-place stepping as well as forward stepping.

The user walks in-place to walk through VE. The user can move in any direction by rocking the knees. Forward virtual motion is achieved by simply walking in place. In this case the knees rock forward then back. To take a virtual sidestep to the right the user lifts his right knee up to the right and then drops it back down (to the left); the left foot should be raised and lowered on alternate steps, but need not rock horizontally. Backward virtual steps are taken by rocking the knees backward first then forward. The user can rock the knees along a diagonal path to move diagonally through VE. The direction and degree of virtual motion is determined by direction and degree with which the knee moves. Virtual displacement is a function of both how far the knees swing and the stepping rate, as physical displacement is a function of both stride length and stepping rate.

Gaiter employs a hybrid sensor system. Position trackers placed on the knees register knee motion. Pressure sensors placed on shoe insoles under the ball and heel of each foot register ground reaction forces. The pressure sensors help determine the timing of each step, punctuating knee motion. Pattern recognition software distinguishes between steps to turn, in-place steps, and actual steps. Since the system can distinguish between them, it can allow the user to intermix virtual and actual steps. Virtual steps move the user in the VE while remaining stationary in the real world.



Gaiter: a new virtual locomotion control being developed at NRL. The user walks in-place to walk through VE. Steps are characterized using a combination of position trackers and pressure sensors

Actual steps move the user the same distance in both the virtual and real world. Actual steps provide the most natural and accurately judged movements but their range is limited, so virtual steps are used to cover large distances.

Features Of Gaiter

Many of the "realistic" features of Gaiter derive from its adoption of leg motion as the control action. It operates in the appropriate coordinate frame of reference: the direction of knee movement with respect to the surrounding environment. Virtual motion may be made in any direction. Sidestepping is an inherent part of the technique. It is compatible with turning the head and body, using the hands for other tasks, a variety of postural movements, and actual walking. The system can be tuned to preserve metrics between physical and virtual space. Knee movement can be scaled and mapped into virtual displacement. The system is responsive; the pattern recognition system does not have to wait for the gesture to be complete before responding to knee movements. Virtual motion occurs as the knees rock. The equipment used to implement Gaiter is compact and relatively inexpensive. A wireless version can be built today, albeit at greater expense than using tethered sensors.

The basic limitation of Gaiter is that walking and running in-place are not the same as actual walking and running. They use somewhat different muscle sets in somewhat different ways. The user does not physically accelerate along the path of motion or build up momentum by running faster in place. (It may be possible to simulate the latter effect by increasing virtual velocity as successive strides are made, but this may make the requisite deceleration seem more artificial.) It will be possible to tune the system to match particular attributes of natural locomotion (e.g., perceived velocity, natural cadence, caloric expenditure, etc.) but it is unlikely that one set of tuning parameters will satisfy all criteria.

Experimental Evaluation

We are currently running pilot studies comparing three different sensor-based virtual locomotion controls: head-based, hand-based, and leg-based (Gaiter). We have started by using the set of locomotion tasks described as part of VEPAB (ARI's VE Performance Assessment Battery [Lampton, Knerr, Goldberg, Bliss, Moshell, & Blau, 1994]). We also have models of the Quantico Village database developed by Paradigm, Inc. for the Team Tactical Engagement System for NAWC/TSD and the Ex-USS Shadwell ship interior developed Dave Tate at NRL [Tate, Sibert, & King, 1997]. This gives us a variety of interesting virtual spaces to walk through. We are tuning the current version of Gaiter to make it match peoples' natural strides. The tasks we will use in the comparative experiment range from simple locomotion down hallways and through rooms, to the more complex task of clearing a building by pointing and clicking at targets while minimizing one's exposure to them. Our hypothesis is that people will perform tasks differently using the three different controls and the sequence of actions (including looking, moving, and manipulation) they perform using the leg-based control will best match the sequence of actions used to perform the task in the real world.

LIMITATIONS OF THE TECHNOLOGY

There are many limitations to the sensors, processing systems, and displays used to construct today's VE systems. Spatial position trackers have a limited range, are sensitive to metal and interference from other sources, and are often tethered. Currently available head mounted displays light weight enough to wear while walking offer a limited field-of-view (typically 50-degrees), a limited display resolution (typically 640 x 480 pixels), a fixed depth of focus, and are often tethered. Current rendering systems provide limited realism of real-time imagery. The lag due to sensor transmission, image generation, and display contributes to motion sickness [DiZio & Lackner, 1992].

There are clearly limitations to the physical interaction provided by VE systems. In terms of locomotion the ground surface is almost always flat, with fixed surface characteristics. This could be improved by employing a hydraulically tilted floor, with adjustable surface compliance. The remaining omission would then be the absence of the collision forces made contacting walls and other raised surfaces. The challenge will be to add these features while keeping the system safe enough to use without falling.

Consequences Of Unrealistic Interaction

What happens when the requirements for interactive realism stated earlier do not hold; when similarity of (1) action, (2) interaction, (3) component actions, or (4) effect are not fully attained? The actions must be the same for the user to develop the right set of coordinated reflexes. The capability (effect) must be the same for users to learn when to apply it, to incorporate it into strategies, and to avoid changing their strategy to *compensate* for its absence. Compensation is bad because it means that users are adopting different practices and approaches in VE than they would use in the real world.

In terms of isolated capabilities, capabilities can be lost in VE, new capabilities can be gained, and the control action can alter the way a capability is used. All of these cases are departures from realistic task performance. If a control lets the user effortlessly move at a rapid speed, the user might carry out rehearsal missions in VE that would be impossible to accomplish in the real world. In terms of interacting capabilities - the control action can preclude other capabilities (e.g., not being able to stop quickly may discourage rapid motion), the control action can free the user to perform extra actions (e.g., a technique that supports backwards motion while the user stands at rest would allow the user to aim a rifle accurately while retreating from the enemy), and the control action can alter the way other capabilities are used (e.g., not being able to advance in a crouching posture limits the kind of ground cover one can hide behind).

PROJECTS USING THIS TECHNOLOGY

Many applications would benefit from the ability to walk through VE in a realistic manner. In the Team Tactical Engagement Simulator (TTES) developed by the Naval Air Warfare Center Training Systems Division (NAWC/TSD) and Southwest Research, military personnel practice urban warfare tactics [Horey Fowlkes, & Reir, 1995; Goodman, Porter, & Standridge, 1997]. The Naval Research Laboratory's Information Technology Division developed a VE of portions of the Ex-USS Shadwell, the Navy's full-scale fire research and test ship, to test the feasibility of using immersive VE as a tool for shipboard firefighting training and mission rehearsal [Tate, Sibert, William, King, & Hewitt, 1995]. Navy firefighters who practiced in the three dimensional model that included fire and smoke effects to simulate actual firefighting conditions performed better than those who only practiced using the ship's diagrams [Tate et al., 1997]. The University of North Carolina's Architectural Walkthrough System allows designers to explore a building design before its construction [Brooks *et al.*, 1992].

DIRECTIONS FOR THE FUTURE

We will continue to refine Gaiter. There are different ways of mapping the characteristics of in-place stepping to virtual stepping. We have initially adopted a linear mapping between the displacement of the knee while stepping in-place to the displacement of a virtual step. Further studies will be carried out to explore how well this matches natural stride lengths and stepping tempo. A variety of criteria will be used to measure the fit including the user's perceived rate of motion, the energy expended, or subjective effort made to move at different speeds.

We are developing an avatar driven by Gaiter. The avatar has two basic uses. It allows the user to see how his body fits into the VE, giving the user a better sense of immersion [Slater Usoh, & Steed, 1995]. An avatar also lets other people see the user's pose and location in VE. The challenge of developing an avatar driven by Gaiter is to match the control actions (in-place stepping) to the controlled effects (virtual stepping) in as natural a way as possible. The match will not be perfect and it remains to be seen how tolerant users will be to different kinds of mismatch.

CONCLUSIONS

There are many interactions between perceptual-motor systems and candidate locomotion controls involving looking, manipulating, turning the body, posturing, and thinking. These interactions limit the most promising approaches to those using the legs to make actions similar to natural locomotion. Our first attempt at building a leg-based control put too high a burden on the user to make special kinds of steps. We combined position trackers on the legs with the insole pressure sensors to create a walking simulator called Gaiter. Gaiter provides a consistent means of taking virtual steps in any direction. We will test our new virtual locomotion technique against two common sensor-based techniques: head-based steering and hand-based steering, both using finger pressure to control speed. The controls will be evaluated in terms of how similar peoples' actions in VE are using the control compared to peoples' actions in the real world.

ACKNOWLEDGMENTS

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Gaiter has been developed and will be refined and evaluated under the ONR 6.2 Virtual Environment Technology program sponsored by Terry Allard and NRL 6.1 base funding in Controls for Synthetic Environments.

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METHODS FOR IMPROVING DEPTH PERCEPTION IN HMDS

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ABSTRACT

Head mounted display systems typically present imagery to the user focused either at infinity (collimated light into the eyes), or alternatively at some nominal finite distance in the order of 11 - 18 feet (diverging light into the eyes). When the imagery presented by an HMD is focused at a finite distance, the right and left eyes are sometimes intentionally set to converge to that same distance. Alternatively, the eyes are often left viewing parallel to one another. In some HMDs the user is permitted to select his or her own preferred focus distance. There appears to be an advantage in improving depth perception in an HMD simulation environment by altering in real time the focus or apparent object distance to match the distance of the principal object or objects being viewed at that time by the user. An eye tracker may be employed to determine where in the scene the user is looking, and the data is fed back to the computer to perform, as appropriate, the refocusing task based on the known distance of the object being looked at. Further realism improvement is likely by changing the convergence as well. This paper will discuss the relative merits of altering the accommodation and convergence as well as the means for accomplishing the refocusing task in the HMD viewing optics rapidly, in real time, and without otherwise altering the image quality or magnification. The net goal is to improve the overall realism of the simulation to the user.

INTRODUCTION

Head-mounted displays (HMDs) have found widespread use in a variety of applications. Their application for pilot training has been especially successful because they are much less expensive and less dangerous than actual flying, and far less expensive to implement than large dome simulators.

To achieve the best results in training, the training environment presented by the HMD should be as close as possible to the actual environment experienced by the pilot. One of the most important improvements in HMDs is the accurate simulation of depth and three-dimensional images.

The need for high quality three-dimensional imaging in flight simulation and other applications has driven the development of various technologies (Okoshi, 1980)). Many of these technologies are fairly complex (i.e. Williams, 1988) and are still far from implementation. As a result the only technique currently being used in such applications is dichoptic (separate image to each eye) presentation of binocular disparity. This paper describes preliminary efforts at OPTICS 1 to improve the realism of HMDs and to determine the merits and viability of adjusting in real time the accommodation or apparent object distance as well as the convergence in an HMD.

SPECIFICATIONS AND REQUIREMENTS

The HMD specifications to which we will work are summarized in Table 1 below. These data represent our best effort at describing a viable and achievable HMD implementation with good performance.

Paper presented at the RTO HFM Workshop on "The Capability of Virtual Reality to Meet Military Requirements", held in Orlando, USA, 5-9 December 1997, and published in RTO MP-54.

Parameter	Specification
Full diagonal field of view	40 degrees
Exit pupil diameter	7mm minimum, 10mm goal
Eye relief	25.4mm minimum
Exit pupil location	Always at eye pupils
Interpupillary distance, nominal	62 mm
Range for interpupillary distance	52 – 72 mm
Distortion	3% maximum
Image blur within horizontal inscribed circle	2.5 minutes of arc maximum
Image blur to corner	3.5 minutes of arc
Spectral band	Visual
Spectral weighting	Photopic eye response
Minimum accommodation distance	15 inches
Maximum accommodation distance	Infinity
Convergence at infinity	Zero
Convergence at 15 inches	9.3 degrees
Speed of change in accommodation	<0.6 seconds
Magnification change over accommodation range	4% maximum
Eye tracker	Yes

Table 1.

VISUAL EFFECTS AND MERITS OF VARYING ACCOMMODATION AND CONVERGENCE TO ENHANCE REALISM

Depth Perception in a Natural Environment

The human mind uses a wide variety of clues to determine distance and depth. These clues include angular extent of an object, occlusion by other objects, perspective, convergence, and accommodation. Each of these clues need to be carefully considered in the complete implementation of an HMD system. However, only convergence and accommodation can be addressed in the physical and optical design of an HMD system, so these will be the only topics addressed in this paper.

Convergence is the rotation of the eyes towards an object. As a person looks at an object, the eyes rotate so that the object is imaged onto the fovea of the retina which is the small region of highest visual acuity. This rotation means that the centerlines of the eyes intersect at the object. Convergence is measured by the total included angle between the eye's centerlines. This angle between the eyes is one of the most important visual clues to depth. Unfortunately for HMD designers, this angle is a function of the user's interpupillary distance or IPD.

Accommodation is the refocusing of the eyes to the distance of the object being viewed.

In a natural viewing environment, accommodation and convergence work together to aid in determining distance. The distance at which the eyes are focussed is the same as the distance at which the eyes' centerlines intersect.

Depth Perception in an Artificial Environment

HMD designers must try to approximate the natural environment depth perception as well as possible. However, they are subject to several constraints which should also guide their design considerations. First, because of the inter-relationship between the IPD and the convergence angle, an exact match between accommodation distance and convergence angle is possible for only a small set of cases. Second, because objects of varying distances may be represented on the same viewing screen, some mismatch between accommodation distance and represented distance is inevitable.

Two measures describe the degree to which an HMD differs from the natural viewing environment. The first measure is called "accommodation error" and is a measure of the difference between the distance at which the eye is focussed and

the distance at which the object is represented. The second measure is called "convergence error" and is a measure of the difference between the convergence angle required by the displayed objects distance and the convergence angle presented by the HMD.

Many difficulties occur when the convergence error and accommodation error are too large. These difficulties include loss of realism, headaches, double vision, blurred vision, and, in extreme instances, even nausea. For small errors, these difficulties tend to ease as the duration of HMD use increases. For larger errors and longer duration of HMD use, however, these difficulties can persist even after the used of the HMD.

Determining the acceptable errors in accommodation and convergence angle is an active area of research. The HMD design community should probably never expect to obtain definitive, universally applicable results for the acceptable errors for several reasons. First, this research is, by definition, very subjective and dependent on the particular experimental parameters. Second, different situations will have different acceptable errors; the requirements on a HMD for a military flight simulator are very likely to be different from those of an inexpensive video game. Third, everyone's visual system is different; a wide variety of common eye conditions can cause people to be unusually sensitive or unusually lax in their tolerance to convergence error or accommodation error. Finally, people have a wide variety of tolerances to non-ideal situations, due merely to their personalities, moods, and temperaments.

To precisely investigate visual effects and merits of varying accommodation and convergence, it is important to precisely define our terms. Accommodation error is

$$A = 1/s_o - 1/s_f,$$

where s_o is the object distance to be represented, s_f is the distance at which the HMD is focussed, and A is the accommodation error. Accomodation error is usually expressed in diopters. (1 diopter = 1/meter) The ideal convergence angle is

$$CA_{ideal} = IPD/s_o,$$

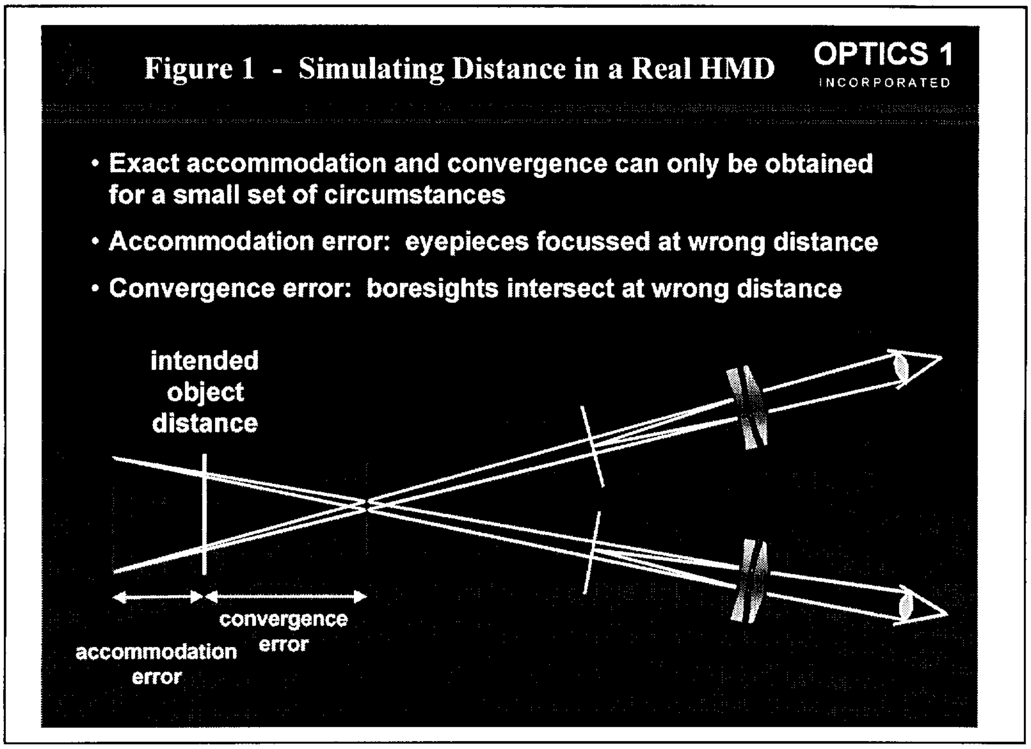
where IPD is the interpupillary distance, and CA_{ideal} is the ideal convergence angle. The convergence angle error is

$$\square_{CA} = CA_{real} - CA_{ideal},$$

where $\square_{CA}$ is the convergence angle error, and CA_{real} is the convergence angle presented to the user. Convergence error can be expressed in either degrees or prism diopters. (1 prism diopter = 0.01 radian = 0.57 degrees).

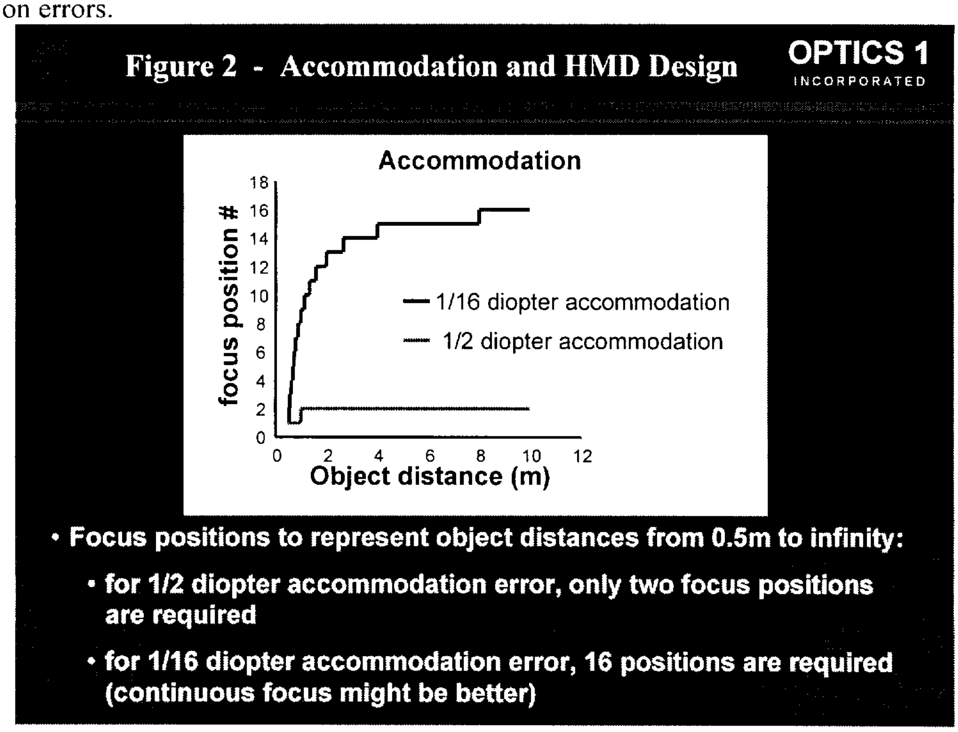
Nevertheless, it is helpful to investigate the requirements of an HMD for various assumptions of convergence angle error and accommodation error.

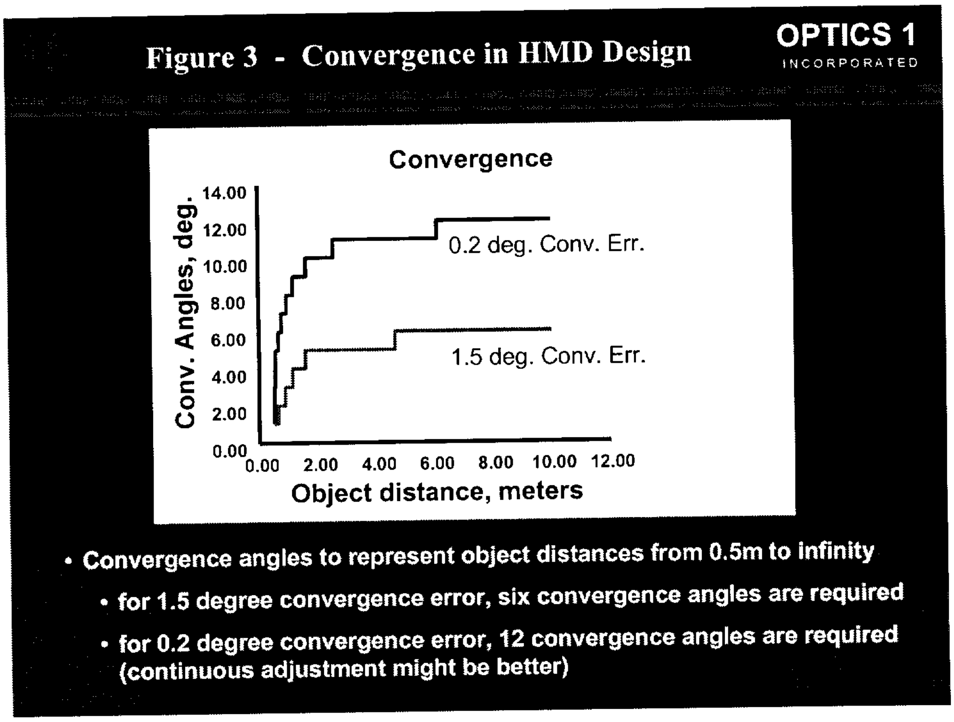
Figure 1 shows how the convergence and accommodation interrelate, and how errors in both can happen.



The top line in the figure shows that, for an acceptable accommodation error of 1/16 diopter, 16 focus positions would be required to represent the range of object positions; for object positions between 0.5m and 2m, a near-continuum of positions is required. The bottom line on the figure shows that, for an acceptable accommodation error of 1/3 diopter, only three focus positions are required. Figure 3 shows the required convergence angles for object distances from 0.5 meter and above. The two curves are for convergence errors of 1.5 degrees and 0.2 degrees.

Figure 2 shows the required focus positions for object distances from 0.5m to infinity for two acceptable accommodation errors.





ACCOMMODATION METHODS

A wide variety of accommodation methods are feasible. These methods include, in no particular order:

1. Translating the lens assembly
2. Translating the display device
3. Translating a sub-group of lens elements
4. The Alvarez asphere, bifocal/multifocal lenses
5. Bifocal or multifocal lenses
6. Liquid filled lens
7. Liquid crystal lens
8. Adaptive optics

1. Translating the lens assembly relative to the display device changes the accommodation distance from infinity to a closer image distance. Presenting images at infinity and at 0.5m requires moving the lens assembly about 3mm for a 35mm focal length lens. This method of accommodation has several advantages, most importantly, it is easy to implement. This method has some disadvantages, too: it requires moving parts. A potential disadvantage is that the exit pupil location where the eye is located may move causing vignetting or clipping of light at off axis field positions.

2. Translating display device switches from a distant image distance to a close image distance by moving the display device from the back focus of the lens to a position inside the back focus. This is similar to translating the lens assembly. It has the advantage of not changing the stop position if the viewing optics is designed to be "telecentric" at the display. Unfortunately, it has a serious disadvantage in that display mounts are usually fairly complex and would be difficult to move.

3. Translating a sub-group of lens elements within the lens assembly switches from a distant image distance to a close image distance by changing the lens assembly's focal length much as in a zoom lens. This method has the advantage that it can be easy to implement and that the moving mass can be very small. Its disadvantages include more complex lens housing and the inherent disadvantages of moving parts.

4. The Alvarez asphere switches from a distant image distance to a close image distance by moving special aspheric surfaces perpendicular to the optical axis. A similar method was used in the autofocus mechanism in the Polaroid Spectra camera. This method has several advantages: only a small mass must be moved, the center of mass does not change, and only a small motion is required. Further, this motion is linear. This method also has several disadvantages: the aspheric surfaces are difficult to fabricate because they are not rotationally symmetric, and the effect on image quality can be unacceptable.

5. A bifocal or multifocal lens can be constructed such than some regions of the lens form a distant image and other regions form a close image. This method is particularly attractive for applications which only require two focus positions, and because no moving parts are required. Disadvantages of this method include lowered resolution and fabrication difficulties.

6. A liquid filled lens has been used in some applications requiring a variety of focus positions. The liquid is held between compliant thin windows that form the outer optical surfaces. As liquid is pumped into or out of the lens, the compliant walls change shape, causing a change in focal length of the device. This method has the advantages of having no moving optical parts and of the potential for quick adjustment times. This method has the disadvantages of a limited accommodation and all the troubles that come with the use of a liquid.

7. Liquid crystal lenses have been used in many applications requiring a quick adjustment in focal length. In a liquid crystal lens, the liquid crystal is placed inside of a lens-shaped cavity. When an electric field is applied to a liquid crystal, the molecules tend to align. Their uniaxial or biaxial symmetry creates a phase retarder. The liquid crystal lens is made without polarizers. Rather than create a quadratic phase variation, researchers have made liquid crystal Fresnel lenses. As voltage is applied to the liquid crystal, its index changes, causing a change in the focal length of the lens. This method has the advantages of having no moving parts, the potential for very fast adjustment speed, and maintaining the correct pupil position. This method has the disadvantage of having a limited accommodation, as well as having all the disadvantages of using a liquid crystal.

8. Adaptive optics are also often used in changing the phase profile of light. Adaptive optics are lenses or mirrors which change shape using a variety of actuator methods. This method has the advantage that a continuous adaptation can be provided. However, adaptive optics usually suffer from the disadvantages of being difficult to control; furthermore, they are a new technology and therefore tend to be expensive.

CONVERGENCE METHODS

A wide variety of convergence methods are also available. These methods include, in no particular order, the following:

1. Video centering
2. Translating the display
3. Tilting the entire assembly
4. Optical wedges in front of the eyes

1. Video centering achieves convergence by electronically moving the center of the scene away from the center of the display device. For example, when simulating the convergence of an object at infinity, the images will be moved towards the nose to create the desired convergence angle. This method has the advantage of having no moving parts and allowing quick convergence times. Its disadvantages include more complex electronics, rotation about the pupil, and the fact that the display must in effect be larger than what is required for any given convergence situation. Figure 4 shows a graphical representation of the video centering methodology.

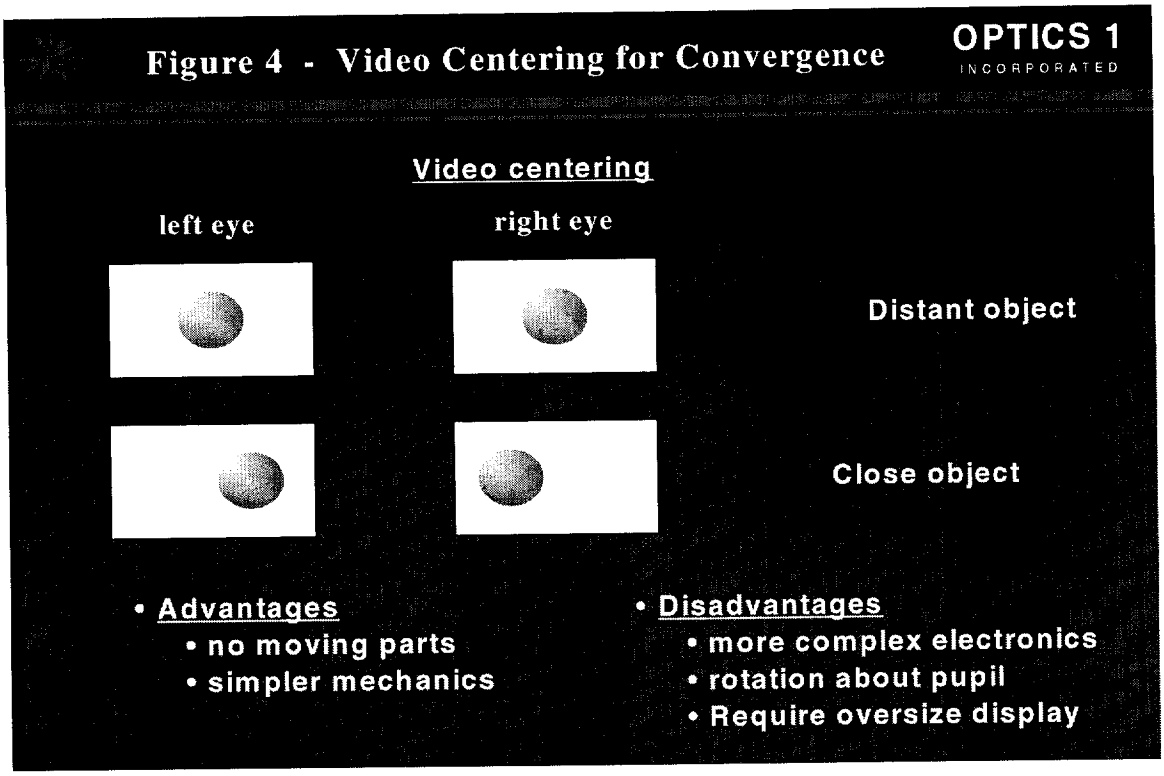


Figure 4

2. Convergence can also be achieved by translating the entire display devices towards the nose. This is often a problem as the electro-mechanical implementation may be difficult.

3. The entire viewing optics assembly including the optics and the display can be tilted to match the desired convergence angle. Ideally this tilt angle should be at about the eye pupil location so as to avoid vignetting or other bad optical effects. While this is a difficult implementation task, it correlates directly with the desired result, making it somewhat attractive.

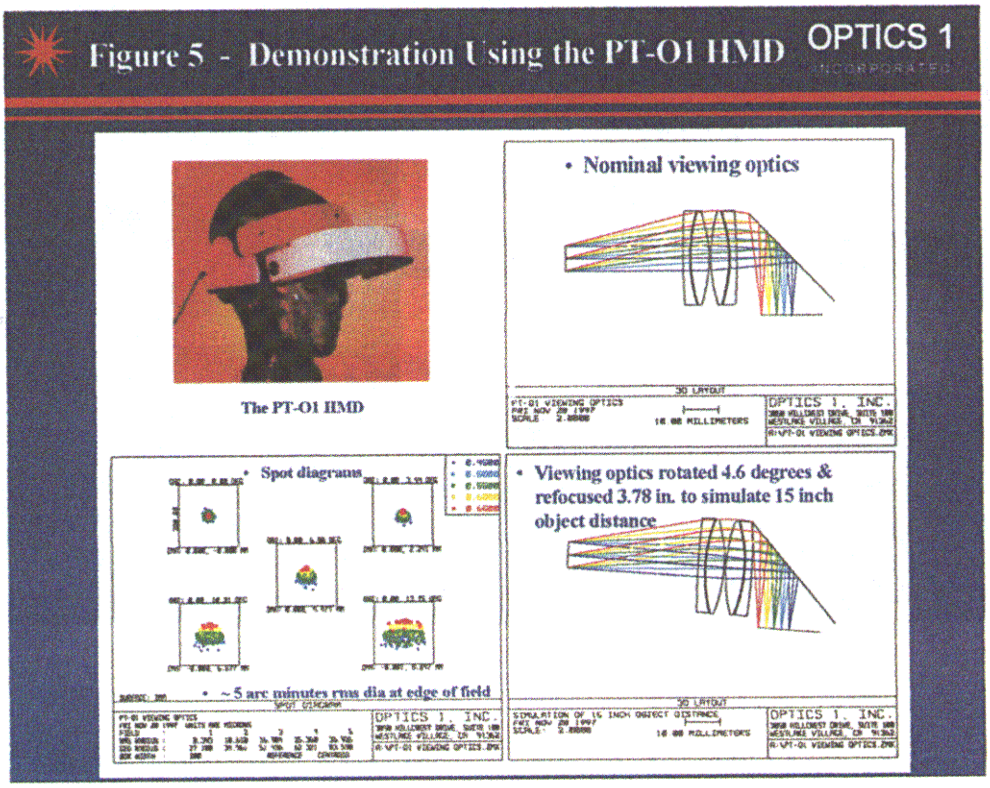
4. We can locate optical wedges in front of the eye so as to vary the magnitude of convergence presented to each eye. If two optical wedges or weak prisms are counter-rotated we can achieve a variable degree of convergence. The disadvantages include the mechanization complexity as well as lateral color or color fringing around objects. A liquid filled variable wedge is also feasible.

EXAMPLE OF A CANDIDATE IMPLEMENTATION

In order to give a realistic example of a viable implementation, we have modified our PT-O1 HMD product in order to allow for a rapid change in both accommodation and convergence from infinity to a distance of approximately 15 inches. This HMD is a commercial product used in video inspection, cinematography, and other professional areas. Its field of view is 27.5 degrees diagonal and thus not ideal for a simulation application, however we used it here due to its availability.

The convergence change was accomplished by rotating the viewing optics and display assemblies in front of each eye by approximately 4.6 degrees towards the nose, and the accommodation was accomplished by refocusing each of the viewing optics lens assemblies by 3.8 mm towards the LCD display device. As it was not possible to rotate the assemblies about the ideal eye pupil location, the performance is not ideal. However, it does demonstrate the feasibility and the overall performance of such an implementation.

Figure 5 shows the lens design for the HMD as well as its optical performance in the form of geometrical spot diagrams. We show that the imagery at the very corner of the field of view is in the order of 5 arc minutes rms blur diameter which is reasonable for this application. We also show the lens assembly and display device rotated towards the nose by 4.6 degrees.



SUMMARY AND CONCLUSIONS

The literature clearly shows the importance of providing the cues of accommodation and convergence in an HMD when used in a simulation environment. This is especially true when the user is in a simulated cockpit or similar environment where imagery of close objects must be simulated as well as imagery of objects at infinity and/or other distances.

We have shown the accommodation and convergence demands for a typical HMD as used in a simulation environment. It is important that the accommodation and convergence demands both be appropriately coupled. Eight different methods for implementation of a variable accommodation and 4 methods for variable convergence in an HMD were presented. The different methods differ from one another in complexity, performance, and other factors. Additional work will be directed towards identifying the optimum system for implementation.

ACKNOWLEDGEMENTS

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CAPABILITY OF VIRTUAL ENVIRONMENTS TO MEET MILITARY REQUIREMENTS

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The DoD and NASA are considering virtual environment (VE) technology for use in forward deployable and remote training devices. Yet, many of these VE devices, particularly those which employ helmet-mounted displays, have an adverse effect on users, eliciting motion sickness and other sequelae (e.g., Pausch, Crea, & Conway, 1992; Kennedy, Lane, Lilienthal, Berbaum, & Hettinger, 1992). These symptoms, now called cybersickness (McCauley & Sharkey, 1992), could retard development of VE technology and limit its use as a training tool.

Motion sickness is known to be polysymptomatic and in scoring self-reports we have found there to be reliably different profiles of sickness in simulators, at sea, in space, and in VE (Kennedy, Lane, Berbaum, & Lilienthal, 1993). Furthermore, recent research in our laboratories implies that cybersickness may involve multiple functional pathways. The first pathway is related to ill-effects upon the autonomic nervous system or ANS (Money, Lackner, & Cheung, 1996). According to sensory conflict theory (Reason & Brand, 1975), the ANS is provoked when sensory inputs from the visual, auditory, vestibular, or somatoceptors are uncorrelated or incompatible. This is the case when one is exposed to the certain sensory rearrangements in a virtual environment. Such rearrangements can trigger the "emetic brain response" (Oman, 1991), causing vomiting, perspiration, nausea, pallor, salivation, and drowsiness.

Slower effects might include the sopite syndrome. This syndrome may involve a sleep-related pathway. Student Naval aviators, referred for airsickness, show that sopite syndrome can occur during military flight training in an individual who is "immune" to airsickness and debilitate an individual long after he has recovered from overt airsickness.

When the ANS pathway is triggered it can also lead to performance decrements. Performance problems can arise due to lowered arousal and decreased concentration or because individuals experiencing ANS symptoms will attempt to minimize ill-effects by modifying their behavior (Hettinger, Kennedy, & McCauley, 1990).

It has also been shown that individuals restrict their head movements while using helmet-mounted displays (Hennesy, Sharkey, Matsumoto, & Voorhees, 1992), and that inhibition of head movement "learned" in the trainer transfers to performance in the actual helicopter. It is clear that if VE systems are to be effective training devices, such negative transfer must be avoided by obtaining a better understanding of the ANS mechanism.

Another cybersickness pathway involves adaptation within the central nervous system (CNS). In a well-respected theory of CNS functioning, von Holst (1954) argues that motor impulses (or efference) leave images in the CNS which are compared to the reafference generated by the effector (i.e., the stimuli resulting from one's own muscular activity). Normally, the efference and reafference images match, thus leading to coordinated muscular activity. When something causes a mismatch, coordinated activities may be degraded (e.g., degraded hand-eye coordination) because of the limiting effects of the reafference. This mismatch can also provoke the ANS pathway, producing motion sickness. Held (1965) and Reason (1978) provide evidence to suggest that the effects of the ANS pathway discussed above can be overcome by facilitating CNS adaptation to these neural mismatches. Regardless of one's opinions about a neural mismatch hypothesis, it is clear that adaptation is fostered when "mismatches" are sufficiently regular, users have control over their movements, and/or they receive a sensory response (e.g., visual, vestibular, or proprioceptive) to their actions.

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Thus, if the sensory rearrangements of the VE are sufficiently small, gradual, regular, and "reafferent", the plasticity of the CNS more frequently allows adaption. This adaptation is characterized by: a decline in the initial response to an altered stimulus; development of an altered, often compensatory response following prolonged exposure to the change; and a continuation of the adapted response (i.e., an aftereffect) once the stimulus is removed (Dolezal, 1982; Parker & Parker, 1990; Welch, 1978). Such post-adaptation aftereffects have been known to persist for several hours after system exposure (Baltzley, Kennedy, Berbaum, Lilienthal, & Gower, 1989; Crosby & Kennedy, 1982; Ungs, 1987) and may occur without any symptoms of motion sickness discomfort except disorientation.

Along the first ANS pathway of cybersickness, if an individual is sick he/she will perceive this discomfort and modify his/her behavior to minimize the ill-effects. Along the second pathway, however, if adaptive changes occur individuals may be unaware of the CNS modifications. Since the two pathways follow a different time course, it is possible for both effects to be present; or either may be present without the other. We will report some preliminary evidence for these predictions.

Much of the research to date on self-reports of sickness symptomatology has used a measure called the Motion Sickness Questionnaire (MSQ). The MSQ was developed more than thirty years ago for studying the causal mechanisms underlying motion sickness. A paper-and-pencil version of the MSQ was later tailored to collect data from simulator participants, and scoring norms were developed using a calibration sample of 1600 simulator exposures. The Simulator Sickness Questionnaire (SSQ) was developed by Kennedy, Lane, Berbaum, and Lilienthal (1993) based on empirical studies. The symptom checklist portion of the SSQ is comprised of 28 symptoms, most of which are rated on a four-point ordinal scale with anchor points at "none," "mild," "moderate," and "severe". The items on the checklist have considerable overlap with the signs and symptom checklist of Lackner and Graybiel. Scoring our checklist by their scoring key versus ours produces Total Scores from the two methods which correlate ($r > .83$) and we showed a figure of our database of two dozen simulators that we use as norms and which are scored also with the Lackner scoring key. We also presented additional normative data for 8,000 exposures from simulators to be compared with data from >450 virtual reality exposures.

In addition to the algorithm for Total Score, the original data base of 1000+ exposures was also used to carry out a factor analysis of simulator sickness symptoms (Kennedy et al., 1993). The symptoms from this large group of exposures revealed three clearly defined factors: nausea and neurovegetative complaints (N), oculomotor disturbances (O) and disorientation effects (D) (cf. also Lane & Kennedy, 1988). These three clusters fit nicely with theoretical descriptions of motion sickness (e.g., Money, 1970; Reason & Brand, 1975) and, for those of us who have personally experienced motion sickness, these three factors have obvious face validity. Compared to the Lackner and Graybiel scoring method, the nausea subscale of our scoring system correlates higher ($r = .88$) with their total score. The total score correlates much lower ($r = .62$) with our disorientation and oculomotor scoring keys. From this factor analytic approach we have therefore hypothesized that if sufficient individuals are studied, it may be possible that the distribution or configuration of the three factors may turn out to be consistent within a given simulator and different between simulators. If so, then perhaps this might provide a method whereby the many different causes of simulator sickness can be delineated. Therefore, while Total Score differences in simulators may index the level of the problem, differences in profile or configuration, REGARDLESS OF LEVEL OF SICKNESS, may signal the nature of the cause of sickness in that simulator.

In a series of 3 experiments, using 3 different scenarios displayed over two different helmet mounted systems, subjects ($N = 75$) were exposed to 20-40 minutes of VE. We found in all three studies:

1) pre post differences in self-report of motion sickness were statistically significant;

2) pre post motor effects (past pointing and/or posture changes) were significantly different;

3) although changes in both types of variables were reliably observed, the sickness severity and size of side effects themselves were not correlated. That means that persons who were sick may or may not have had postural effects and the converse.

These data were compared and discussed with several other cases in which different aspects of motion sickness, while perhaps not totally independent, are clearly not isomorphic. This independence of function persists generally across other situations in which motion sickness is elicited (e.g., after space flight). If so, any independent and uncorrelated

aftereffects should be assessed individually as each may have different safety implications. Furthermore, independence of function would imply different pathways and perhaps different centers of control.

In conclusion, we propose that there at least two major pathways involved in cybersickness, each exhibiting different performance and safety problems during a motion challenge. We believe that the time course of each pathway needs to be systematically measured. Such empirical knowledge may enable us to avoid triggering the ANS pathway by using brief bursts of exposure, while simultaneously promoting CNS adaptation during repeated and carefully limited exposures.

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MOTION SICKNESS SIDE EFFECTS AND AFTEREFFECTS OF IMMERSIVE VIRTUAL ENVIRONMENTS CREATED WITH HELMET-MOUNTED VISUAL DISPLAYS

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ABSTRACT

We have investigated side effects and aftereffects evoked by moving the head to interact with a virtual environment (VE) shown in a helmet mounted visual display (HMD). The graphics computer of such a VE must monitor the HMD's spatial orientation and position in order to present images from the proper perspective. Delays between head movements and image updating cause aberrant visual motion of a virtual world. We found that above delays of 40 ms motion sickness and postural instability are evoked minutes after head movements begin. The severity of side effects is a function of the latency between head movement and visual update delay. Fifteen minutes of making head movements in a VE with a 254 ms delay causes motion sickness severe enough to make 28% of subjects withdraw from the situation. Users appear recovered 15 minutes after VE exposure ends if they remain immobile, but normal activities quickly revive their motion sickness symptoms, indicating that they were sensitized by exposure to visual update delays. We conclude that visual update delays are a unique cause of side effects and aftereffects in VEs utilizing HMDs.

INTRODUCTION

Virtual environment (VE) technology has many potential applications but current technology leads to side effects and aftereffects for users. Motion sickness is an acknowledged problem in VEs (DiZio & Lackner, 1992, 1997; Wilson, 1996) that needs to be solved because it is aversive and hinders performance of normal activities after the user leaves the VE.

We have attempted to document the incidence and etiological factors of motion sickness side effects and after effects associated with a prevalent VE configuration which utilizes an HMD. For experimental investigation, we developed a facsimile of the VESUB system developed at NAWC-TSD in Orlando, Florida for training naval candidates to navigate a surfaced submarine in a harbor. Subjects view a virtual harbor scene from the perspective of a surfaced submarine. One sub-goal of both VESUB and of real officer of the deck training, is for the user to develop spatial awareness by scanning the environment for signs and landmarks spread out over 360°. Therefore, the VESUB system and our experimental system utilize HMDs, which enable presentation of a panoramic view of the virtual world from a perspective that can be adjusted by glancing about in a natural manner.

The scenery of a virtual world in an HMD is carried around by the head instead of staying fixed like the real scenery. In such VEs, head position is monitored by a tracking device and fed to a graphics computer which updates the user's perspective and computes the proper image for the HMD display units. This gives the appearance of a stable virtual world and appears to contribute to the sense of immersion in the VE (Deisinger, Cruz-Neira, Riedel, & Symanzik, 1997). However, the process is imperfect in practice because of delays in the tracking device, the transmission of tracker signals, graphical computation and rendering time and others. These delays cause aberrant slippage of the retinal image when a head movement is made. That is, the HMD images commence moving later than the head and continue for a latent period after the head movement is complete.

In flight simulators utilizing large screen displays, motion sickness and postural instability are prevalent side- or aftereffects, but head movements per se have never been identified as etiological factors (Kennedy, Hettinger, Lilienthal, 1990). In our VE, the first and most obvious thing we noticed was that users rapidly became motion sick when they looked about wearing the HMD but did not complain if they kept still while viewing a stationary virtual world. The only visual motion in our VE was brought about by delayed updating of the visual scene in the HMD during head movements. Thus, we launched an effort to determine whether visual update delays associated with head movements are a specific cause of side-effects and aftereffects in VEs utilizing HMDs.

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VE SYSTEM CHARACTERISTICS

VE computer and software: The virtual environment we experimented with was generated with a Silicon Graphics ONYX Reality Engine II computer (SGI). The virtual world was a harbor scene from the perspective of the sail of a surfaced submarine. The boat was still in the water, and there was no wave motion or any other external visual motion. The harbor channel was marked by buoys in the water and range markers on land. Geographic features, clouds and the water surface provided ample visual contrast. The HMD model we used was a LEEP Cyberface II. The LEEP has LCD displays 479 pixels wide by 234 high and uses optics which preferentially magnify the periphery of each LCD image. We used a psychophysical technique to determine that the LEEP FOV is 128° wide by 74° high, with 30° of binocular overlap. We calculated an angular resolution per pixel of 9.8 arcmin in the center graduated to 19.5 arcmin at the edges. In all our experiments, the rate of computing video frames was 30 Hz. The devices we used to track HMD position were a Polhemus 3SPACE FASTRAK magnetic device with a 19.2K baud serial interface or a custom-made mechanical device connected directly to the VME bus via an A/D board. We measured the end-to-end visual update delay of the system with both tracking devices. A PC computer recorded signals from photometric devices picking up activity directly from the HMD display units and angular rate sensors on the HMD shell, while the VE was running on the SGI. The minimum delay we could achieve between onset of HMD movement and image movement on the HMD displays was 67 ms with the Polhemus and 21 ms with the mechanical device. We purposely added delays to the VE with a software ring buffer in order to achieve an adequate range of experimental visual update delays.

EXPERIMENTAL PARADIGM

Two separate experiments were conducted. The first experiment assessed motion sickness severity at visual update delays of 67, 159, 254 and 355 ms utilizing the Polhemus tracking device. Twenty one subjects participated in all conditions. Seven new subjects were recruited for the second experiment in which motion sickness severity was assessed at update delays of 21, 39, 80 and 163 ms, achieved with the mechanical tracker.

Experimental exposure to the VE lasted 15 minutes, split into five 2 minute sequences of head movements divided by 1 minute periods for rest and recording of motion sickness symptoms. In the 2 minute sequences, a pre-recorded audio tape announced landmarks in the VE for the subject to look at every five seconds (24 total movements). The required head movements ranged from 12° to 180° amplitude in the horizontal plane, between 25° up and 15° down in pitch. Subjects had been shown an aerial view of the virtual harbor before donning the HMD in order to familiarize them with the landmarks. The subjects stood while doing the task and most of the HMD's weight was supported by long elastic cords. Typically, subjects took less than one second to turn to a new target, using a combination of eye, head and torso rotation and sometimes shifting their feet, and then they stood still until the next landmark was called.

Acute symptoms of motion sickness were evaluated according to the criteria of Graybiel, Miller, Wood & Cramer (1968). The checklist derived from this scale measures five cardinal signs and symptoms of motion sickness, including nausea, pallor, sweating, salivation and drowsiness, and additional qualifying symptoms such as headache, dizziness and eye strain. Scores in the 8-15 point range indicate severe malaise. The checklist was filled out after each two minute sequence of head movements in the VE and 15 minutes after leaving the VE.

MOTION SICKNESS SIDE EFFECTS IN THE VE

Figure 1 illustrates the most severe motion sickness recorded during the 15 minute VE exposure period, for both experiments. The severity of symptoms increases monotonically as a function of the visual update delay. Analysis of variance indicated significant effects of visual update delay: $F(3, 60)= 10.43$, $p<.0001$ in Experiment 1 (67, 159, 254, 355 ms delays) and $F(3, 18)= 7.11$, $p<.0067$ in Experiment 2 (21, 39, 80, 163 ms delays). The severity of symptoms is significantly greater than zero at every delay except 19 ms ($p<.03$ at least, individual t tests). The ratings register from mild malaise on the Graybiel scale at 39 ms to moderately severe malaise at 355 ms. The severity of motion sickness seems to asymptote between 254 and 355 ms (no significant difference between these two). In the 254 ms delay condition, 6 of 21 of subjects (28%) refused to complete the full 15 minute exposure because they were too close to vomiting. The full spectrum of symptoms was reported in all conditions.

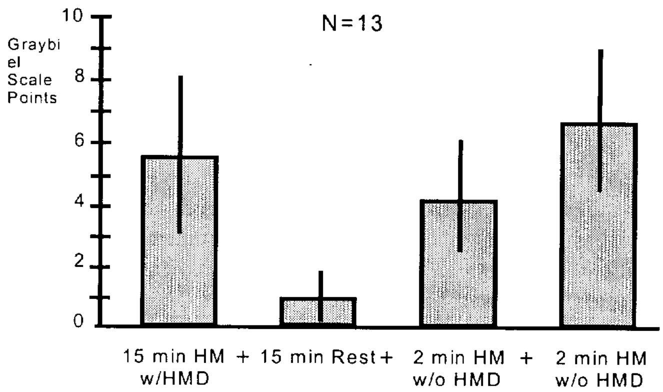

Figure 1. Motion sickness elicited by voluntary head movements (HM) in the initial 15 minute exposure to a VE with a 254 ms delay in update of the HMD image, after 15 minutes of rest without the HMD, 2 minutes of HM in a natural environment and 2 minutes in the VE again.

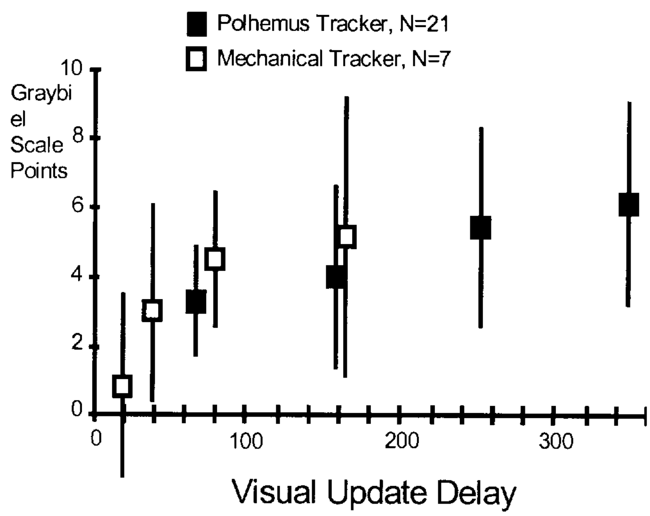

Figure 2. Motion sickness severity as a function of visual update delay, in VEs created with two different tracking devices. The plot shows the maximum severity rating evoked during 15 minutes of intermittent voluntary head movements.

MOTION SICKNESS AFTEREFFECTS

A preliminary analysis of the first 8 subjects indicated that motion sickness symptoms had abated almost entirely in 15 minutes after the VE exposure period was over and the subjects had been resting quietly. Therefore, we asked the remaining subjects after the 15 minute rest period to perform two additional head movement sequences, guided by the same 2 minute tape recorded directions as before.

In the first post-rest sequence, the HMD was not worn and the location of VE landmarks was marked by tags placed on corresponding locations in the real laboratory environment. As soon as the motion sickness symptoms were recorded, the subjects donned the HMD again and made another 2 minute sequence of head movements in the VE and reported symptoms a final time. The extra conditions were only done after the 254 ms delay VE exposure. Figure 2 illustrates the complete pattern of results for the 13 subjects who completed all conditions.

The motion sickness severity experienced by this sub-sample during 15 minutes in the VE was 5.7 points, which is similar to the value of 6.2 for the whole sample. Fifteen minutes after leaving the VE and resting in a normal

environment the malaise level was only 1.0, not significantly above zero. Subsequently performing head movements in a natural environment for 2 minutes brought the motion sickness score back up to 4.4 points, which was significantly above 1.0. Returning to the VE and making head movements for 2 minutes brought the symptom level up above the level of the original fifteen minute exposure, to 6.7points.

CONCLUSIONS

The results indicate that motion sickness is a serious potential side effect and aftereffect of using a HMD as a visual interface to interact with a VE. Motion sickness severe enough to convince subjects they might vomit can be elicited within minutes of exposure to the VE. Users experience no motion sickness unless they move their head to scan the environment. In the VEs we studied, there was no simulated motion of the user's base of support or of other objects. The only visual motion was generated by voluntary head movements. Thus, head movements are a sufficient cause of motion sickness in VEs incorporating HMDs. This is not the case in flight simulator.

Overt motion sickness decays quickly after a 15-minute VE exposure is over, but users remains sensitized. Anecdotal reports indicate the period of sensitization is much longer than the 15-minute period in which we have done formal evaluations; up to hours is possible. During the sensitized period, even normal activities can bring the symptoms back, and returning to the VE escalates symptoms immediately to the prior maximum level or above.

Lags between head movements and compensation of the image in the HMD are a powerful etiological factor in this form of motion sickness. Such lags distort visual motion of the virtual world during head movements. The motion is distorted in the sense that the normal coordination of the vestibulo-ocular and optokinetic reflexes does not result in stabilization of the retinal image. The magnitude of aberrant visual motion and the severity of motion sickness both increase in proportion to the visual update latency. A latency of 19 ms is below threshold for eliciting motion sickness, under the conditions we tested.

These findings can aid in ameliorating or circumventing motion sickness in VEs. They suggest that careful measurements of end-to-end visual update delay of VE systems is necessary to anticipate and circumvent side effects. To avoid motion sickness, users can limit their head movements, VE designers and engineers can strive for sub-threshold visual update delays, or the power of human sensorimotor adaptation can be exploited.

We are currently attempting to define other etiological factors and side effects that must be take into consideration. Our results indicate that postural instability is another serious side effect/aftereffect and that the field of view, weight and spatial resolution of an HMD as well as the computation rate of video frames are other etiological factors.

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HUMAN BODY MODELING AS A HUMAN FACTORS ENGINEERING TOOL

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Computer based human body modeling provides a tool with which human factors issues can be assessed early in a system's design. By populating an interactive visualisation of a design with representative mannequins issues such as fit, reach and vision can be evaluated and design changes recommended at the concept stage. Body modeling tools are continually advancing, offering increasingly sophisticated dynamic representations of the human operator. For the influence of these tools to spread further, they must minimise the demands placed on their users. The user requires a consistent, stable tool which answers the traditional questions of human factors evaluation at an early point in the design cycle.

INTRODUCTION

The task of the human factors engineer is to match the design of systems to the requirements and capabilities of their human users. Effective equipment design must balance a range of constraints whilst seeking to meet the product's goals. A growing engineering approach has been to use computer aided design (CAD) as a means of testing alternative solutions to the design problem. For usability to be considered during product development it is necessary to represent the capabilities and constraints of a system's human component within this design process. Human body modeling can support this requirement by providing the human factors engineer with a tool that is compatible with the CAD focused design methodologies of product developers.

Virtual reality (VR) now allows dynamic mannequins to be interactively fitted and manipulated within three dimensional models of system concepts. This offers a means of assessing and presenting ergonomic issues at an earlier point in the product lifecycle than previously possible. Identifying and correcting design conflicts at this early stage offers savings in time and money. The process of product design and specification can often be faced with user uncertainty, the instability of user requirements, and a communication gap between the designers and the users. Computer modeling starts to address these problems by allowing user evaluation of the virtual prototype as the basis of defining and refining a common concept of the required system.

There is a widespread perception of VR in which the user puts on a headset to enter an alternate reality. This bears little relation to the current use of body modeling for human factors evaluation. Although many of the tools available will output to a stereo headset, these systems tend to be viewed through a desktop screen. Whilst immersive evaluation of a design promises to be a powerful medium for considering the user's perspective, the benefits of immersion do not, as yet, offset the cost and limitations of its supporting technology. Despite this, the emergence of desktop VR tools has raised the potential for applying novel techniques to human factors evaluation and input to design. Whilst the immersive interface promises another level of model experience, the true value of these environments centres on their ability to visualise and interact with a populated concept model, for which desktop presentation is adequate. Immersive displays do not currently offer an advantage for the core human factors tasks of analysing fit, reach and vision for a given population.

THE HUMAN MODEL

Modeling the human remains a major challenge to the development of virtual worlds. Whilst inanimate objects such as buildings, machines and landscapes have been convincingly simulated for many years the representation of organic forms, particularly the human, has presented a greater obstacle. The inherent complexity and the absence of uniformity associated with organic forms has made them difficult to simulate both visually and in terms of their behaviour.

Synthetic environments have advanced to provide detailed interactive worlds in which simulated forces can interact over a distributed network. Representation of the human within these environments have tended to either group the human

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within an aggregate force or relegate the user to a simplified component of a more easily simulated entity such as a tank, a plane or a ship.

Recognition of the influence of human behaviour and capability on the real world activities on which synthetic environments have been modelled has led to work to improve the representation of the human.

The Centre for Human Sciences' (CHS) Integrated Performance Modeling Environment (IPME) project seeks to shape the performance of synthetic environment entities based on an integrated set of human performance models. Other work within DERA is looking to incorporate human performance factors within the emerging command agent technology. Great improvements have been made to the visualisation of dismounted infantry within SEs with entity models such as DI-Guy (Boston Dynamics). Whilst the domains of human modeling for SEs and body modeling for workplace analysis are largely separate, they are each working to enhance the human model and may in the future meet in the middle.

The functional complexity of the body model required for workspace assessment depends on the aims of the evaluation. At its most basic, a line of sight assessment could be made by positioning your views of the environment at the operational eye heights for your range of users. Whilst offering an initial assessment, this overlooks the figure's dynamic interaction with the environment such as sitting in a chair or turning to see a display. By using a fully articulated human figure it is possible to make a more complete evaluation of the environment taking into account access, fit, reach, vision, etc. within a system model in a way which relates to the methods and design principles regularly practised in the ergonomic evaluation of hardware prototypes and completed systems.

COMMERCIAL BODY MODELING TOOLS

A wide range of commercial body modeling tools are available. At the lowest level, it is possible to buy a selection of static mannequins to populate architectural models. Whilst these figures are intended for presentation purposes they might be considered to aid the evaluation of a design by illustrating an area's intended usage. At the other extreme advanced biomechanics models are available which allow the user to develop and analyse musculoskeletal models (Musculographics, Inc.). Between these extremes there are a number of tools which offer dynamic body models for the purpose of design evaluation. An outline of some of these tools is provided in Table 1.

Android	(Mechanical Dynamics) A graphical human body model for the ADAMS CAD system. The software enables the user to create human models to study kinematic, static, and dynamic behaviour.
COMBIMAN	(CSERIAC) An interactive CAD model offering body size and proportions for Air Force and Army pilots. Provides a tool for reach, strength and vision analyses. Human model is based on a 35 segment representation of the human skeletal system.
Crew Chief	(CSERIAC) A derivative of COMBIMAN which provides an interactive CAD model of an aircraft maintenance technician. The model takes into account body size, posture, clothing, strength and vision for evaluating designs for their ease of maintenance.
ERGO	(Deneb Robotics, Inc.) A module of the Deneb CAD modeling toolset which offers rapid prototyping of human motion within the work area. The model incorporates forward and inverse kinematics for limb manipulation.
JACK	(Transom) Jack is a high fidelity human model which is able to interact with the virtual environment. Features include walking, grasping, eye tracking, animation, collision detection and dynamic strength. The environment provides advanced visualisation features such as lighting and mirrors.
Kinemation	(Alias Wavefront) Three dimensional character animation through forward and inverse control of the skeleton. Includes a behavioural model for its skin model linked to time or the skeletal position.

MannequinPRO	(HumanCAD) A development tool to create human mannequins for import to other CAD packages such as AutoCAD. Allows user to create a range of body size characteristic and postures, outputting a static model.
MDHMS	(Boeing) The McDonnell Douglas Human Modeling System (MDHMS) is an in-house body modeling tool which includes a three dimensional animated human mannequin. The system provides articulated limbs and inverse kinematics for the simulation of assembly, operations and maintenance.
Poser	(Fractal Design) A body modeling tool offering a range of body sizes and body types. Although intended as a visualisation tool, it supports interactive body posture and limb control and allows the output of static CAD models.
Safework	(Genicom) A detailed human model whose features include animation, vision analysis, collision detection, and posture analysis leading to a comfort score. The model allows user alteration of critical variables, adjusting the other anthropometric variables based on statistical variations.
Sammie	(British Technology Group) A body modeling environment offering anthropometric and morphological control for the analysis of fit, reach, vision and posture.

Table 1. Commercial Body Modeling Tools

Computer Aided Workplace Design at the CHS

Computer aided design at the CHS started with the acquisition of the Sammie software tool in the late '80s. The Sammie system provided the vehicle ergonomics group with a virtual environment in which an articulated figure could be scaled to represent key anthropometric measurements. The mannequin could then be placed within a skeletal model of a proposed operating environment such as a vehicle crewstation. Figure 1 shows the Sammie mannequin positioned within a concept crewstation which was designed and evaluated by the group using this tool prior to the construction of an experimental crewstation.

After mastering the precise command set and syntax of its UNIX operating system, necessary to run and maintain the software, the user had to overcome a cumbersome interface to manipulate the mannequin within the virtual environment. The system was full of promise, offering a method of viewing and evaluating a concept environment from the perspective of a representative user. However, the time and effort required to set up a populated environment for evaluation reduced the number of occasions on which computer modeling could be justified over paper based techniques and hardware mock-ups.

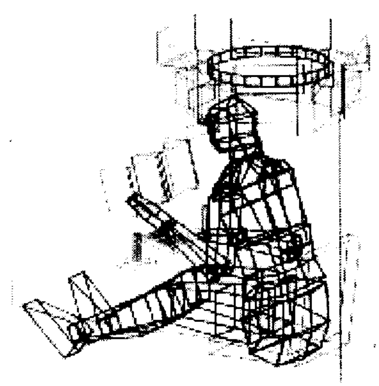

Figure 1. Sammie Mannequin within a Concept Crewstation Model

Despite the limitations of the group's early body modeling tools, the recognised potential for improved input to the product design cycle led to their subsequent acquisition of the JACK body modeling tool. Improvements in affordable computing power, JACK's enhanced anthropometric model, its more usable interface and its advanced functionality were considered to counter many of the limitations of earlier systems. Continual improvements to the modeling tool and to the power of its host computer platforms have led to a gradual rise in its application to specific human factors design projects.

The group has explored the extent to which the body modeling tool can be usefully applied. Designs evaluated using this tool include a hand held imaging device, the control panel for a remotely piloted vehicle, office environments, crewstation designs, and a harbour traffic control room.

Figure 2 shows a virtual world generated in the body modeling environment to assess a control room. At one level, design alternatives to the control room were assessed against considerations such as furniture design, inter-operator communication and the position of display screens. In addition, it was important to consider the controllers' primary display, the room's windows. A simplified model of the harbour was generated in addition to the redesigned control room supporting an evaluation of the design's influence on the visibility of the shipping lanes.

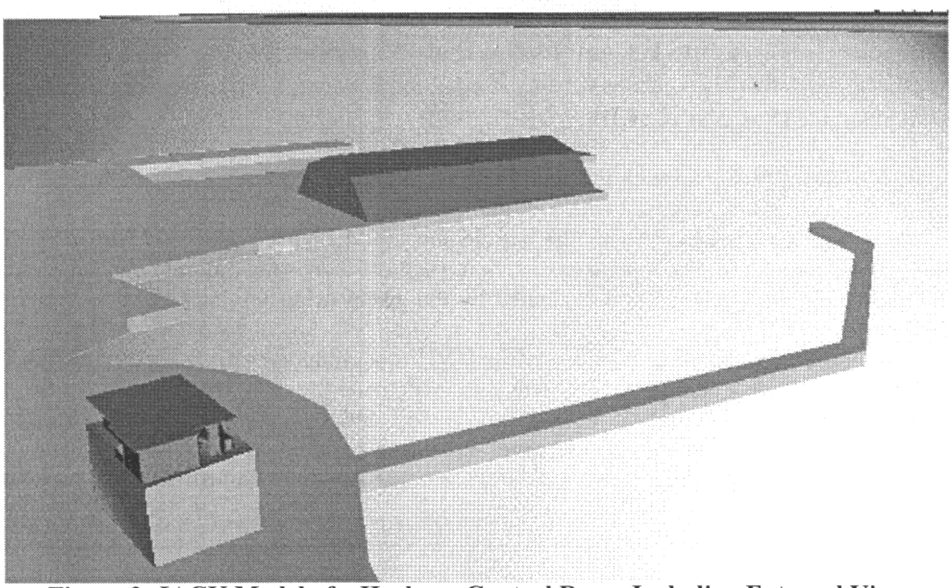

Figure 2. JACK Model of a Harbour Control Room Including External View

The utility of body modeling tools is not limited to design evaluation against human factors guidelines. Figure 3 illustrates a detailed model of a closed circuit television control room modelled and evaluated by CHS. Interactive control and animation of a human mannequin within this environment supported a standard analysis of fit, reach and vision within the proposed room. Techniques such as texture mapping and shadowing helped to quickly build a realistic representation of the environment. By visualising the environment, the model offered an accessible medium for the stakeholders to develop a common design concept. The model was used by representatives of the designers and the users to review the environment and interactively make changes to its proposed design. At the same time, the knock-on effects of these changes were assessed from a human factors perspective. This process led to the gradual evolution of the design as alternatives were prototyped and iterated.

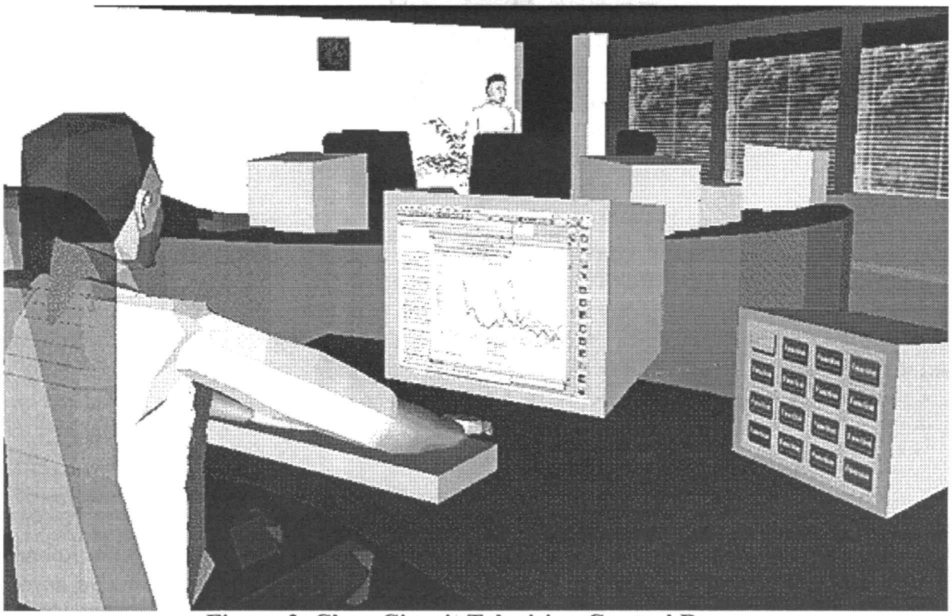

Figure 3. Close Circuit Television Control Room

USER REQUIREMENTS FOR BODY MODELING TOOLS

The cases described illustrate real applications of body modeling as a tool to provide human factors input within the design process. Computer based body modeling is a relatively recent technique and there is considerable scope for improvement to the tools. The value of this technique has provided the motivation to work within the shortcomings of its supporting tools. There remain many reliability, usability and functionality issues relating to the tools applied within CHS which currently inhibit their wider use.

Reliability

Workspace evaluation requires the body modeling tool to be consistent, stable and valid. The user needs to be confident in the tool's ability to repeatedly provide an accurate interactive model of the human and its environment. Human body models have tended to increase in complexity in order to provide a more accurate representation of the individual. However, the multiple degrees of freedom which characterise the joints of the human body place significant processing demands on the software simulation. When interactively manipulating a mannequin within a 3D model, these models must balance the constraints of the mannequin's skeleton with the constraints of the environment and the instructions of the tool's user. There is a risk that small variations in position and action will lead to a wide variation in mannequin response. This can reduce the apparent realism in movement of the human figure. In addition, these inconsistencies challenge the use of these tools for workspace evaluation which relies on a degree of repeatability before conclusions can be drawn concerning fit and reach. Furthermore, the increase in the number of calculations performed during simulation raises the risk of software failure. The effort invested in developing an environment and an associated evaluation procedure can be quickly lost in a software crash. The effect of this can be a loss of confidence in the tool leading to a more narrow application of the tool's advertised capabilities for future projects.

USABILITY

The usability of these tools has been greatly enhanced by the improving cost to power ratio of computer hardware. It is now possible to display and interact with fully shaded 3D models. Past human modeling relied on wire frame representation of the environment which was often difficult to interpret. Despite these improvements, the overall usability of these tools tend to fall short of their potential. An apparent side effect of increased processing power has been an increase in the overt functionality of these tools. In some cases the user is faced with a range of functions, each requiring the definition of numerous obscure attributes before a mannequin behaviour can be implemented. Whilst increasing control over the simulated human is a positive goal, the manner of its implementation is critical. It should not be necessary to alter balance controls in order to manoeuvre a mannequin onto a seat. These tools need to automate fine control of the mannequin with the option of a manual override by the user at any point or level of detail.

Control within 3D virtual environments remains a difficult problem to solve. Most systems allow mouse control, modulated by holding down combinations of the mouse or keyboard keys to control movement in each axis. Other devices such as joysticks and space balls offer an alternative without offering a truly intuitive interface. 3D position sensors such as the polhemus system (Polhemus) allow the mannequin to mimic the limb movements of the user but remain an expensive and cumbersome solution. A further alternative is provided by an instrumented physical mannequin called the "Monkey" (Digital Image Design Inc.) which, when linked to the body modeling tool, allows direct manipulation of the human model.

Despite these control options, human body modeling remains a cumbersome tool. When evaluating a design, certain questions are asked such as, can the population reach control A?, or can the population see screen B? For these tools to reach their potential, they must provide answers to these questions with the minimum of effort on the part of the user. One approach to achieving this is to provide the mannequin with a working understanding of the environment. For example, it should know what a chair is and how to sit on it. It should know what a screen is for, how to turn it on and whether it is in a comfortable position. What is needed is for the computer to take on the labour intensive tasks of mannequin control to free up human effort to consider the information provided by the tool.

Functionality

Whilst expanding functionality has been highlighted as a potential hindrance to usability, enhancement of the human body model could help to improve tool usability and user confidence, particularly where added complexity is hidden from the user. Continuing efforts to improve the reliability and consistency of these tools require the improvement of existing functions such as collision detection and the development of new functions such as a method of arbitrating between the numerous inputs to the model to achieve consistency in the mannequin's actions. All of these advances will be diminished if they are not implemented in way that is sensitive to the users' requirements.

Work to enhance the model of human performance and behaviour within synthetic environments is one area in which the human body model could be developed into a more powerful human factors tool. For example, current evaluations require the expert to make a judgement of the user's ability to operate in an environment for a prolonged period. By including and improving human behaviour and performance models for mannequins it may become possible to define operational scenarios to test variables such as temperature, fatigue and stress when considering a proposed layout. Models of attention and information processing capacity could be used to highlight features of a design which might lead to an insupportable load under situations of high activity or a likelihood of error during periods of low activity.

Although initially rejected by this discussion, the potential contribution of immersive interaction within the virtual body modeling environment may provide new insights to design once the technology has matured sufficiently. The ability to experience a proposed environment from the perspective of a 97th percentile maintenance technician or even through the eyes of a visually impaired operator has the potential to demonstrate the importance of accounting for variation, both human and situational, in design in a new and powerful way.

CONCLUSION

Human body modeling provides the human factors engineer with a new tool which ties together the opportunities of computer aided design and the user centred techniques of prototyping and iterative design. It was stated at the start of this paper that "the task of the human factors engineer is to match the design of systems to the requirements and capabilities of their human users." It seems reasonable to expect this goal to be prominent in the design of the tools offered to support this process. Continued efforts to improve these tools along these lines should secure the place of this technology as an important tool for supporting a human factors input to design.

INFORMATION LINKS

Alias Wavefront, Kinemation, http:/www.aw.sgi.com

British Technology Group, Sammie,
http:/lut.ac.uk/departments/cd/docs_dandt/staff/porter/sammie.html

Boeing, MDHMS, http:/boeing.com/

Boston Dynamics, Inc., DI-guy, http://www.bdi.com/html/di-guy.html

CSERIAC, COMBIMAN & Crew Chief, http://cseriac.udri.udayton.edu/products/

Deneb Robotics, Inc., ERGO, http://www.deneb.com/ products/ergo/ergo.html

Defence Evaluation and Research Agency, Centre for Human Sciences, http://www.dera.gov.uk/

Digital Image Design Inc., The Monkey, http://www.didi.com/

Fractal Design, Poser, http:/www.fractal.com/poser/poser.html

Genicom, Safework, http:/www.safework.com/index.html

HumanCAD, MannequinPRO, http:/www.humancad.com/

Mechanical Dynamics, Android, http://www.adams.com/mdi/product/modeling/modeling.htm

Musculographics, Inc., Musculographics, http://wwwmusculographics.com/

Polhemus, The Polhemus Sensor, http://www.polhemus.com/

Transom, JACK, http:/www.transom.com/

HOW REAL ARE VIRTUAL ENVIRONMENTS?: A VALIDATION OF LOCALIZATION, MANIPULATION AND DESIGN PERFORMANCE

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ABSTRACT

Immersive simulation techniques such as Virtual Environments (VE) can revolutionize human factors engineering and training projects provided that they are carefully validated. Is human performance in the virtual world the same as in the real world? When visual aspects perceived on a virtual ship differ from those perceived on a real ship, human factors engineering studies may yield non-optimal designs. When interactions with virtual worlds are not natural, training may not transfer to the real world.

I will discuss three studies that compared human task performance in real and virtual (HMD) environments. First, we carried out spatial perception experiments and measured localization performance: how well can people indicate the center point between two objects in identical virtual and real environments. Second, manipulation performance was measured: how well can people grab, turn and position objects in virtual environments and what adaptation effects occur when returning to the real world. Third, we compared the assessment of ergonomic aspects of identical virtual and real ship bridges.

Discrepancies found between the results for the real and the virtual bridge are discussed in terms of challenges with respect to the quality of head-mounted display optics and tracking devices and, most importantly, with respect to natural interfaces needed for manipulation (virtual hand control) and for moving around in virtual worlds (intuitive navigation methods).

SPATIAL PERCEPTION IN VE

This study focused on the quantification of spatial perception in virtual environments as a quality measure for realism and functionality. The accuracy of spatial positioning tasks was psychophysically quantified for subjects in an immersive visually simulated environment: a 5m x 5m Engine Control Center of a Dutch M-frigate. Performance in the real environment was compared with the performance of identical tasks in its virtual counterpart.

One type of task (bisection) was to position a hand-held pointer at an imaginary bisection point between two markers in 3D space (separated 2m to 6 m). Another type of task (positioning) was to position the pointer at a certain distance from the wall. Virtual space was simulated using a Polhemus' Fastrak head-tracking device, Evans and Sutherland's ESIG 2000 high performance image generator (64 ms delay time) and an Eyegen 3 head-mounted display (colour, stereo, a 40 degree field of view).

The typical distance between indicated and actual bisection points was approximately 20 cm in the real versus 30 cm in the virtual environment (a 50% increase in errors). Positioning tasks show an even higher increase in errors (approximately 90%). These data show that our 3D spatial bisection and positioning tasks are sensitive to the impairment of spatial perception in (high performance) virtual environments due to a simultaneous decrease of spatial resolution, field of view and/or delayed visual feedback. In a separate experiment it was shown that field of view alone was not responsible for the degraded performance in VE. Further, experiments in a virtual environment with only isolated markers in an empty environment show that subjects integrate environmental structure spatially for optimal positioning performance. The detailed modelling of environmental structure appears to be an important property of virtual (and probably of real) environments.

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MANIPULATION PERFORMANCE IN VE

The application of Virtual Environment techiniques in training projects often requires a high-level natural interaction with the environment. Virtual hand control is the most natural manual interaction method called direct manipulation. Direct manipulation allows users to grasp, rotate and move virtual objects with a realistic virtual hand that mimics the real hand. Such intuitive manipulation methods potentially enable advanced applications in the field of interactive design, training, medicine, etc. However, they should be carefully evaluated.

We have studied manipulation performance in virtual environments using direct (virtual hand control) manuplation compared with indirect (mouse driven 3D cursors) manipulation. These manipulation methods were tested under monoscopic and stereoscopic viewing conditions. Participants were asked to discriminate, grasp, pitch, roll and position virtual objects. Both speed and accuracy of manipulation tasks were measured.

Virtual hand control proved to be significantly faster (35%) and more accurate (40%) than 3D mouse cursor control. Virtual hand control affected more head movement which was available in both conditions. Head movements induce motion parallax (a powerful visual depth cue). Further, it was shown that the speed and accuracy of manipulations strongly improve under stereoscopic viewing conditions. Stereoscopic viewing also significantly increased the sensitivity to size differences between objects (50% better).

ADAPTATION OF EYE-HAND COORDINATION IN VE

Above we mentioned that performance (speed, accuracy) of direct manipulation (virtual hand control) is much faster and far more accurate than that of indirect manipulation (traditional mouse driven 3D cursor control). However, in current virtual environments the virtual hand may not always be exactly aligned with the real hand due to imperfect optics or due to tracking errors. Such misalignment may cause an adaptation of the users' eye-hand coordination and possibly a decrease in manipulation performance compared to aligned conditions. Therefore, we have studied visuo-motor adaptation as well as performance decrease under misaligned virtual hand conditions using a prism adaptation paradigm.

Participants were immersed in an interactive virtual environment with a deliberately misaligned virtual hand position (a lateral shift of 10 cm). We carried out pointing tests with a non-visible hand in the real world before (pre-test) and after (post-test) immersion in the virtual world. A comparison of pre- and post-tests revealed after-effects of the adaptation of eye-hand coordination in the oppositie direction of the lateral shift (negative after-effects). The magnitiude of the after-effect was 20% of the lateral shift under stereoscopic viewing conditions. Interestingly, decreased manipulation performance (speed/accuracy) during the immersion with misaligned hand compared to aligned hand conditions was not found. The occurrence of negative after-effects in lateral direction indicates lower level parameter adjustment of eye-hand coordination. This is promising for those interested in using virtual hands to acquire visuo-motor skills. Acquired skills in VE are likely to transfer to the real world.

DESIGN TASKS

By order of the Royal Netherlands Navy, TNO developed and evaluated a prototype VE-system which enables the interactive 3D design of operational areas of a ship and which offers a wide range of specific human factors engineering tools. The evaluation of the prototype system focussed on the functionality and validity of the system. We have evaluated the VE-system on the basis of a series of tests carried out by eight subjects on the virtual bridge of the Hr.Ms. Mercuur. For verification purposes, the results of the tests on the virtual bridge were compared with those obtained with identical tasks on the real bridge. First, we tested reachability for examining the perceptual and geometrical quality of the proto-type system. Second, accessibility was tested to quantify the speed and ease of navigation and obstacle avoiding in VE. Third, we tested how well participants could manually grasp and position a bearing-compass given a set of ergonomic constraints.

Results showed serious perceptual deformations of spatial dimensions in the virtual environment for all tests. Misperceptions may be partly explained by imperfect head-mounted display (HMD) optics. For the other part, modeling and tracking problems must have caused the problems. Further, objects in the virtual environment (VE) were not always recognizable and in some cases appear to be (or are) different from the real environment (RE). This caused serious discrepancies between the results of our design task in VE and RE.

We also found that accessibility studies in VE take significantly longer than in RE and that subjects collide with obstacles in VE far more often in VE than in RE. This finding is likely to be due to the relatively narrow field of view of current HMDs and to non-intuitive navigation methods.

These results indicate that virtual environments have to be very carefully modeled and in sufficient detail before they can be used for evaluation tasks such as reachability and accessibility tests. Furthermore, head-mounted displays have to be carefully tuned to the properties of the human visual system using high quality optics. Feedback delays should be reduced. Finally, new, more intuitive methods for navigating in VE may improve a user's sense of orientation in VE and the functionality of accessibility studies.

Knowledge of flaws (as emerging from the current validation studies) enables us to correct VE models and display techniques such that human factors studies can be safely carried out in VE. When thoroughly validated, VE can be a powerful tool for even more advanced human factors engineering studies (reachability, accessibility, interactive design) than the ones that have already been carried out successfully with VE (view, layout). The benefits of VE in terms of participation, risk reduction, cost reduction and design optimization are evident.

INTERFACE ISSUES IN THE USE OF VIRTUAL ENVIRONMENTS FOR DISMOUNTED SOLDIER TRAINING [2,3]

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ABSTRACT

In 1992 the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) initiated a program of in-house experimentation to investigate the use of virtual environments (VE) technology to train dismounted soldiers. Since that time, we have conducted thirteen experiments examining human performance in VE, training effectiveness and transfer of skills acquired in VE to the real world, and side-effects and after-effects of exposure to VE. The tasks used have included distance estimation, tracking, object manipulation, visual search, route learning in buildings, building search, and land navigation. This paper summarizes results from these experiments related to visual display characteristics and methods of locomotion.

The most common VE display systems, low- to moderate-cost head mounted displays (HMDs), limit performance with low resolution and small fields of view (FOVs). Performance on a variety of distance estimation tasks is significantly worse than performance on similar tasks in the real world. Providing stereoscopic view improves performance, but only at short distances. Increasing the field of view while holding resolution constant improves performance. Linking the viewpoint to head movements improves distance estimates and, under some conditions, spatial knowledge acquisition. For some tasks, performance using a monitor is better than performance using an HMD, while on other tasks, the reverse is true.

A variety of methods have been used to simulate walking in VE: joystick, spaceball, treadmills, and walking in place (with instrumentation to sense steps). Few direct comparisons of these methods have been made. For some tasks, a joystick combined with auditory cueing may provide an effective substitute for high-cost locomotion simulators.

INTRODUCTION

In 1992 the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) initiated a program of in-house experimentation to investigate the use of virtual environments (VE) technology to train dismounted soldiers. Since that time, we have conducted thirteen experiments examining human performance in VE, training effectiveness and transfer of skills acquired in VE to the real world, and side-effects and after-effects of exposure to VE. The tasks used have included distance estimation, tracking, object manipulation, visual search, route learning in buildings, building search, and land navigation. We have now reached the point in our program where it is necessary to synthesize what we and other researchers have found, draw conclusions, and make recommendations for the use of VE for Army training. We are now beginning that that process. While our primary interest is in the use of VE for training, it has been clear from the start that it would be necessary to pay particular attention to the human computer interface. This paper will present some preliminary conclusions about two types of interface devices: relatively inexpensive visual display devices and devices for the simulation of locomotion.

The original program objective was to improve the Army's capability to provide effective, low-cost training and rehearsal for Special Operations Forces and Dismounted Infantry through the use of virtual environments technology. Subgoals were to: focus on the requirements for individual soldier and leader accomplishment of unit tasks; determine the necessary characteristics of VE technology, including fidelity requirements; and evaluate transfer of training and performance to the real world. While we have consistently pursued these objectives over the life of the program, we have found them to be more complex than originally anticipated.

We describe our research program as a progression up the levels of a pyramid. Following an initial analysis of the task requirements for dismounted soldier training, and a review of the previous research in the use of VE for training (a very sparse area when we began), we conducted four experiments to investigate interface effects on the capabilities of participants to perform simple tasks in VE. Variables investigated included the type of control device, amount of practice on the tasks, stereoscopic vs. monoscopic helmet-mounted displays, and type of display device (monitor, boom, or helmet-mounted display). At the next level, we conducted two experiments that addressed the effectiveness

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of VE for teaching the configuration of and routes through large buildings, and the transfer of the knowledge acquired to the real world. Taken together, these results led to an originally unplanned program of research into the investigation of distance estimation in VE. At the third level, we investigated the use of VE to represent exterior terrain, both for training land navigation skills (identifying landmarks and learning routes), and assessing threats. Research at the top of the pyramid (we have combined the top two levels) is investigating the use of VE for training team tasks. This experimental series is just beginning.

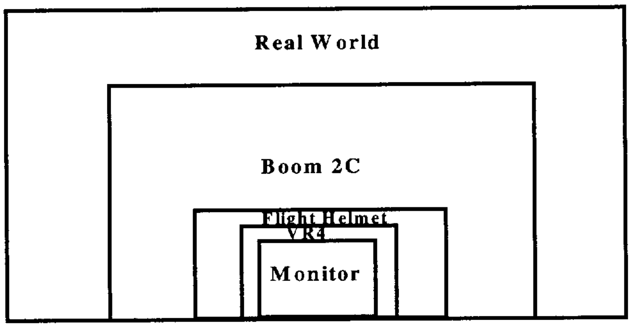

Figure 1. The relative sizes of the fields of view of various VE display devices

This paper will address two sets of interface devices: visual display devices and locomotion simulators:

There are four major characteristics of HMDs that seem particularly important:

- Resolution
- Field of View (FOV)
- Stereoscopic Vs. Monoscopic Vision
- Presence or absence of Head Coupling.

HMDs that we have used include the FakeSpace Labs BOOM2C, the Virtual Research Flight Helmet, and the Virtual Research VR4. HMDs differ in their use of color (the BOOM2C uses only two colors, not three), their resolution, and their FOV. Figure 1 shows the proportional size of the field of view of these HMDs relative to the normal human FOV and a 20" monitor viewed at a distance of approximately 24". Note that use of these devices restricts peripheral vision. The resolution of the displays is poor. Administration of an acuity test in VE has resulted in mean Snellen acuities of 20/500 and 20/860 for different versions of the VR Flight Helmet, and 20/200 for the BOOM2C (Lampton, Knerr, Goldberg, Bliss, Moshell, and Blau, 1994; Lampton, Gildea, McDonald, and Kolasinski, 1996).

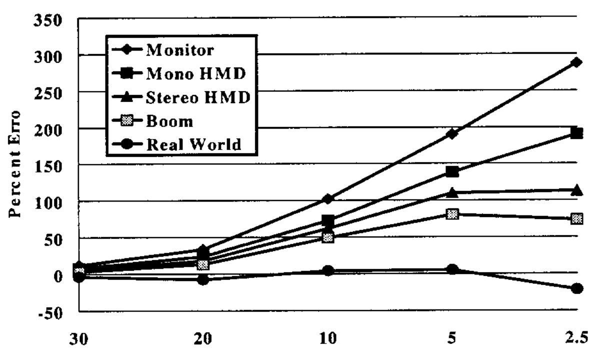

Figure 2. Percent error in distance estimates as a function of display device

VE DISPLAYS AND DISTANCE ESTIMATION

To determine the impact of these factors on performance in a realistic task, we developed a distance estimation task in which the human participant estimates the distance to a human figure as it moves toward them from a known distance of 40 feet. We did this with a number of different display devices in VE (using a virtual image of the human figure) and in the real world with a live human. Figure 2 combines the data from several different experiments (Lampton, Knerr, Goldberg, Bliss, Moshell, and Blau, 1994; Lampton, Gildea, McDonald, and Kolasinski, 1996; Singer, Ehrlich, Cinq-Mars, and Papin, 1995). Errors in the VE are in the direction of underestimating the distance to the figure (i.e., reporting it as being closer than it "actually" is). This seems to be consistent across all of the distance estimation tasks that we have used, with one exception to be described later. Significant differences among display devices are found more-frequently at the shorter distances. Performance generally improves with the increases in the field of view and resolution. Stereoscopic presentation improves performance only at distances shorter than 10 feet.

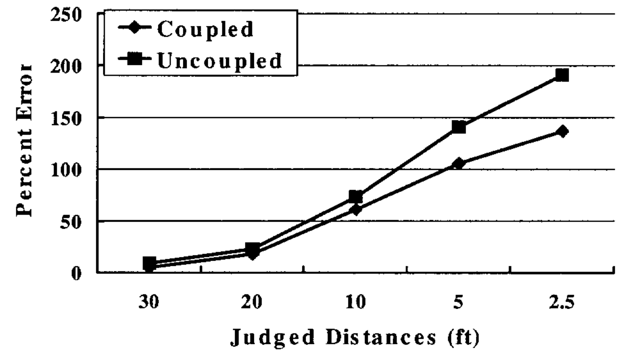

Figure 3. Percent error in distance estimates as a function of head coupling

As shown in Figure 3 head-coupling, or linking the field of view to head movements, also improves performance at the shorter distances (Singer, Ehrlich, Cinq-Mars, and Papin, 1995).

In order to examine the factors affecting distance estimation in VE more closely, and perhaps develop ways to improve distance estimation, Witmer and Kline (in press) used several other tasks. Figure 4 shows the results of an experiment in which participants were asked to estimate the distances to cylinders placed in a corridor at distances from 10 to 110 feet away. They underestimated the distances in both the real and virtual worlds, but underestimated them less in the real world.

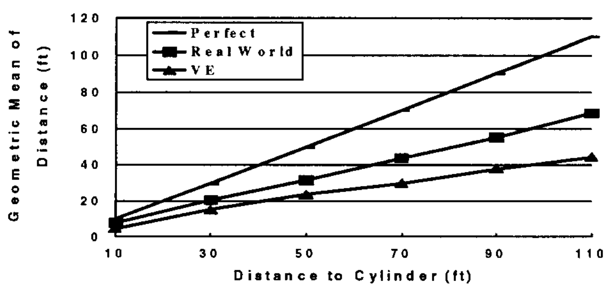

Figure 4. Distance estimates to a stationary object in a VE and the real world

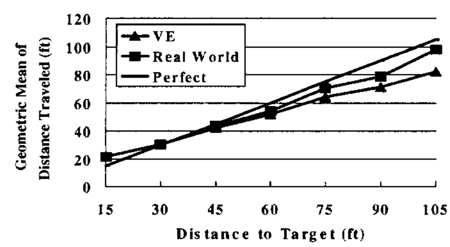

Figure 5. Distance traveled as a function of target distance

To what extent are these results due to participants' inability to provide good numeric distance estimates in any environment? Witmer and Sadowski (in preparation) used a different approach that asked participants to walk blindfolded to a target that they had just seen, instead of reporting the distance verbally. Participants in the real world condition viewed the targets, then walked the distance in a hallway. In the VE condition, they used a treadmill to walk a simulated hallway. Again, the participants underestimated the distances to the targets in both the VE and the real world (Figure 5).

They underestimated them more (i.e., were less accurate) in the VE. We can be confident, therefore, that these errors in distance estimation are not some artifact of the use of verbal reports of distance. However, it is interesting to note

that the overall level of performance was better in this experiment than in the one described immediately before. Distance traversed in VE was about 85% of the true distance, while the verbal reports of stationary observers in the previous experiment were about 50% of the true distance.

It is difficult to examine the effects of the display device characteristics on human performance because we are limited to the characteristics of existing displays, which tend to differ on multiple dimensions, not just a single one. However, Kline and Witmer (1996) were able to use a software mask to create a smaller FOV for the BOOM2C, without changing any other characteristics. In this experiment, participants were placed in the VE in front of the end of a corridor (facing a wall), and asked to judge the distance to the wall. There was no corresponding real world condition. As shown in Figure 6, the narrow field of view condition (60 degrees horizontal x 38.5 degrees vertical) produced worse estimates than the wide field of view condition (140 degrees horizontal x 90 degrees vertical). It was the only condition in these experiments in which distances were overestimated in VE. A probable cause is the that the narrow field of view causes the loss of perspective cues which are important for distance estimation in this situation.

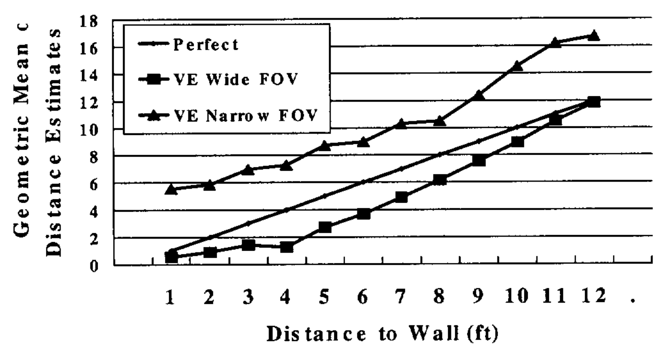

Figure 6. Distance estimates as a function of viewing distance and FOV

VE DISPLAYS AND PERFORMANCE ON OTHER TASKS

Other experiments have looked at how display characteristics affect performance on tasks other than distance estimation. Lampton, Gildea, McDonald, and Kolasinski (1996) compared a monitor, the BOOM2C, and the Virtual Research Flight Helmet in terms of performance on five tasks. Body movement and orientation were controlled by a joystick, with head coupling available for the HMD and Boom conditions only. The tasks were:

- Search -- Searching a room for a flying object while seated in the center of the room.
- Turns -- Moving through a narrow corridor which made a series of alternating left and right turns.
- Doorways --Moving through a series of rooms.
- Tracking --Moving a joystick-controlled pointer to a fixed target.
- Bins --Using a joystick to place an object in the correct bin.

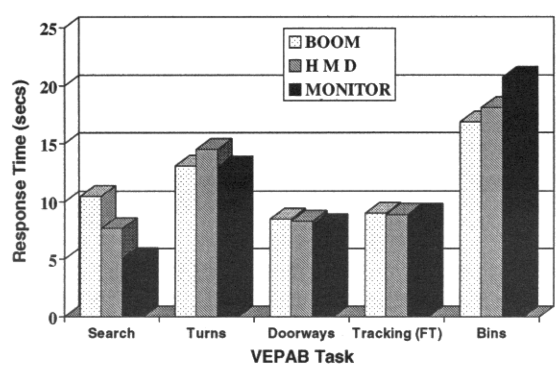

Figure 7. Time to complete selected VEPAB tasks as a function of display device

As shown in Figure 7, there were significant differences among these devices on only one task, the search task. Today's college students, perhaps because of their experience with video and computer games, appear to be quite proficient in searching a room while viewing it in a monitor and controlling their point of view with a joystick. The data are also a reminder that adding somewhat unstable mass to the head tends to affect head movements.

Simulating Locomotion in VE

Lampton, Knerr, Goldberg, Bliss, Moshell, and Blau (1994) compared the joystick and a spaceball to control locomotion through a variety of simple environments. Some involved "flying", and others did not. On every locomotion task, movement was significantly faster with the joystick (Figure 8)

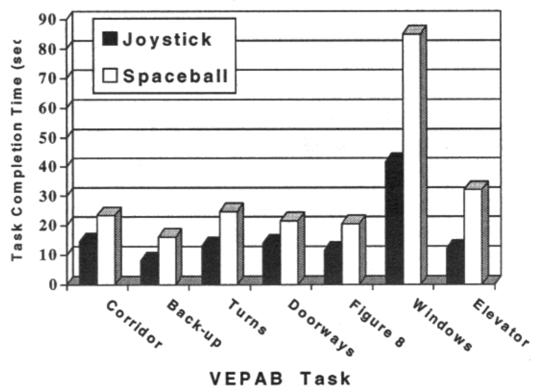

Figure 8. Locomotion task performance as a function of control device

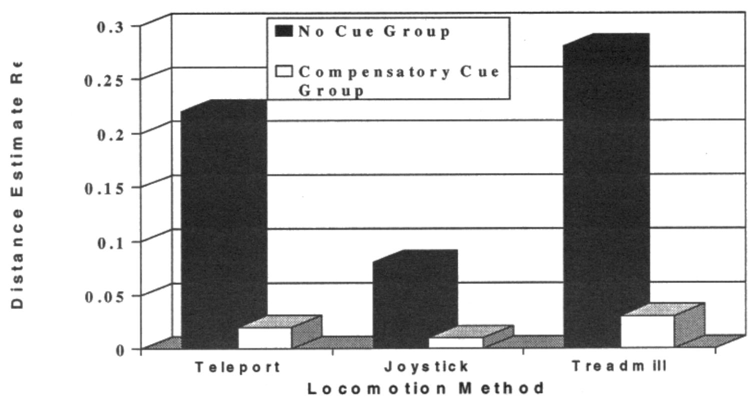

Figure 9. Error in distance estimates as a function of locomotion method and compensatory cueing

They attempted to keep travel time constant for all groups. The joystick moved participants forward at a fixed speed when pushed forward. Teleportees waited the same amount of time as moving the route by joystick required before they were teleported. Treadmill participants were instructed to maintain a fixed speed, and were automatically given recorded verbal reminders if their movement varied from that standard. When the auditory cues were present, the three groups did equally well. In the absence of auditory cues, the joystick group did best, and the treadmill group did the worst. The visual movement cues that the joystick group received are believed to be responsible for their superiority to the teleport group. The poor performance of the treadmill group is attributed to the workload required by the secondary task that they were given, that of maintaining a constant speed.

While much of the research has taken place in the simulated indoors, both simulated and real outdoor terrain were used in the investigation of spatial knowledge acquisition in VE. In the first experiment (Singer, Allen, McDonald, and Gildea, 1997), college students navigated one of two terrain areas, stopping at various locations along the route to

learn to identify various landmarks. After the training, they were tested by being placed at new locations and asked to point to and estimate the distance to the same landmarks. There were three training conditions:

- High VE, using a head coupled HMD and the treadmill
- Low VE, using the same HMD, but without head coupling, and a joystick
- Map study

The performance of the college students, in terms of landmarks correctly located, was straightforward. The Hi-VE condition was significantly better than the map condition, with the Low-VE condition somewhere in between (Figure 10).

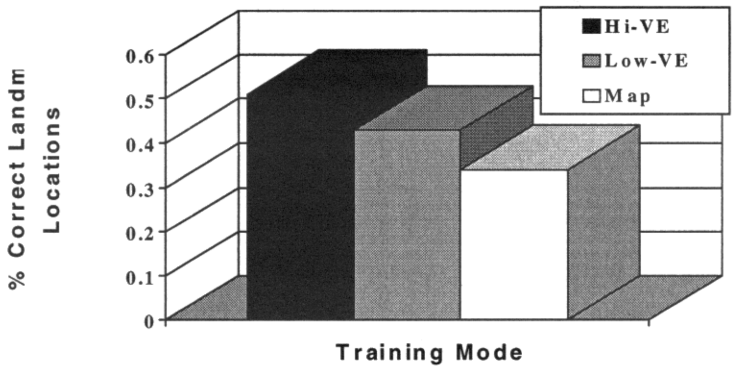

Figure 10. Percentage of landmarks located correctly as a function of training mode

In the second experiment (Singer, Allen, McDonald, and Fober, in preparation), soldiers at Fort Benning, GA performed the same task using a moderate fidelity representation of an actual training area. They used either map study or a mid-level VE interface (head-coupled HMD with joystick control of movement). In addition to being tested in the VE, they were also tested on the actual terrain. The performance of soldiers (Figure 11), when tested in the VE, is consistent with that of the students, although there was only one VE condition. The VE group did better than the map group.

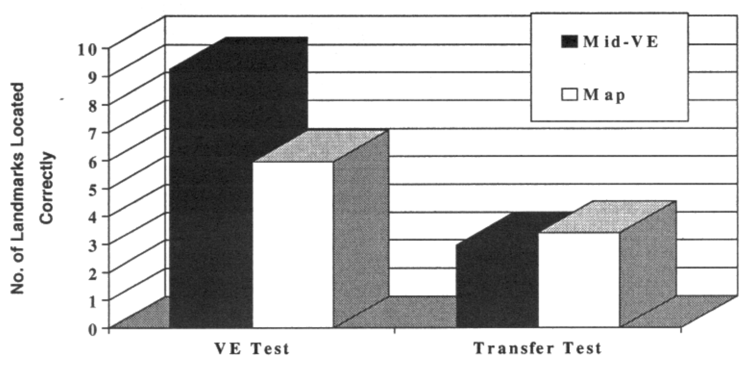

Figure 11. Number of landmarks correct identified by soldiers in VE and on the actual terrain

However, on the transfer test, which was performed on the actual terrain, there was no difference between the groups. Moreover, as is common in studies of transfer of training from simulation devices, both groups did worse on the transfer test than they did on the VE test. There are several possible explanations for this. First, the soldiers were all Army officers who were experienced at relating maps to terrain, but not at relating computer–generated visuals to actual terrain. Second, perhaps the terrain database was not sufficiently like the actual terrain. While it was topographically correct, the color and visual texture were not necessarily correct. Generic plants were photo-textured, and were not the correct height or color. Some re-grading and planting was done, and vegetation grew, between the

time the information for the database was collected and the experiment was conducted. Participants may have incorrectly focused on the specific vegetation cues, rather than the terrain contours and roads. This suggests that either lower fidelity (obviously generic vegetation) or higher fidelity (more like the actual views) approaches might be more effective. In contrast to exterior terrain, Witmer, Bailey, and Knerr (1996) found very good transfer of knowledge about building interiors from VE to the real world.

CONCLUSIONS

Conclusions Regarding Visual Display Systems

- VE performance is worse than real world performance on a variety of visual tasks. Contributing factors are likely to be FOV and resolution. The consequences of limited FOV are less well understood than those of limited resolution.
- Distances in VE are typically underestimated.
- Stereoscopic displays improve performance only at short distances.
- Head coupling may or may not improve performance, depending on the task performed.
- Image fidelity is a consideration for transfer.

Conclusions Regarding The Simulation Of Locomotion

- The method used to control self-motion in VE can affect the perception of distance, but not always in the ways we would have predicted.
- Compensatory cues can improve distance perception in VE.
- Because of the influence of computer and video games, young people may be generally proficient in the use of a joystick, and may find it a very "natural" means of locomotion.

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DEVELOPMENT OF A VIRTUAL ENVIRONMENT SOFTWARE TESTBED USING COMMERCIAL-OFF-THE-SHELF SOFTWARE COMPONENTS

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INTRODUCTION

The goals of the Virtual Environment Training Technology (VETT) program are to develop, demonstrate and evaluate the use of virtual environment (VE) component technologies for navy training applications. A key part of this effort is the development of a testbed, performed by Management Systems and Training Technologies (MSTT), for investigating the benefits of using VE interfaces to improve naval training while reducing training-system costs. This paper describes the technology components integrated by MSTT that provide a tool for training effectiveness research at the Naval Air Warfare Center Training Systems Division (NAWCTSD) in Orlando, Florida. The development approach used for the testbed is to integrate off-the-shelf tools into one cohesive software platform. Applications developed on the testbed include a multi-modal Virtual Electronic Systems Trainer, a spatialized audio location task, and relative motion experiment for surface ship handling. Current efforts on the testbed are directed towards open-water and restricted maneuvering surface ship handling.

BACKGROUND

Many VE-based testbed systems have been developed and reported on in the virtual environment research community (Appino, Lewis, Koved, Ling, & Codella, 1992, Pausch, Burnette, Conway, DeLine, & Gossweiler, 1994, Bricken, & Coco, 1993, Shaw, C., Green, M., Liang, J., & Sun, Y. 1993, Davidson, 1996, Davidson, 1997). A review of such efforts provides a baseline in developing requirements for a rapid-prototyping, reconfigurable software testbed. Based on past research, Table 1 reveals some key features that should be considered in the development of a VE-research testbed.

Performance	Design
SS Smoothly generated images -Database organization -Efficient processing by renderer	Performance Measures -Data collection, recording, playback and analysis of session data
Lo Low tracking latency -Communication overhead minimized -Predictive techniques implemented -Continuous sampling makes tracking data readily available	Co Reconfigurable -Database-driven models/process configuration
Low event latency -Sensory events are synchronized without noticeable delay to the user	Device Independence -Database definitions of device types/mounting/units of measure -API is free of device dependencies
Di Distributed processing -One machine/processor per task	Portable representations across heterogeneous platforms -ASCII file definitions of various representations
Ef Efficient communication -Low overhead	Extendible database tools for adding new properties to objects

Table 1. VE Testbed Performance and Design Criteria

Paper presented at the RTO HFM Workshop on "The Capability of Virtual Reality to Meet Military Requirements", held in Orlando, USA, 5-9 December 1997, and published in RTO MP-54.

VETT TESTBED FUNCTIONAL COMPONENTS

MSTT's approach in creating the VETT software testbed is to use software components from Division Inc., Entropic Research, SensAble Technologies, Paradigm Simulation, and Dynasim AB to provide the needed software capability. Division Inc. provides the necessary database infrastructure, communications, and processes to create basic VE applications. Entropic Research provides tools for speech recognition. SensAble Technologies provides hardware and software to simulate sensory input involving touch. Dynasim AB specializes in object-oriented simulation and provides the needed capability to simulate symbolic systems of equations, and Paradigm Simulation provides DIS and marine effects capabilities. C++ is used for in-house process development, and UNIX Systems Lab's C++ Standard Components Library is used to provide common tools for software development.

The most difficult aspect of testbed development is the integration of other subsystems so that the use of added features is transparent to the user and software developer. Figure 1 shows all the major functional components of the VETT testbed. The simulation system, speech recognizer, haptic interface, data collection, record/replay, and augmentations to the visual renderer are all new servers that have been added to the basic VETT kernel. The following sections provide brief descriptions of the testbed functional components.

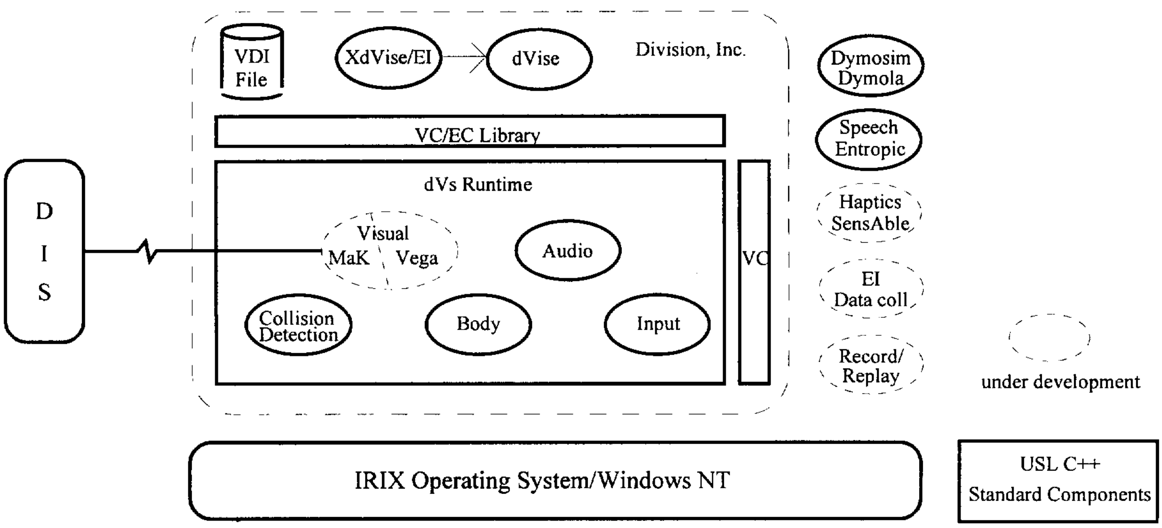

Figure 1. VETT Testbed Software Components

TESTBED INFRASTRUCTURE (Division Inc.)

dVS Runtime. The VETT testbed infrastructure is built on the dVS Runtime/dVISE software environment from Division Inc. It provides a standard suite of "Actors" that are typically required by all VE applications. The dVS Runtime includes processes to support visual rendering, sound spatialization, collision detection, 3D position tracking, and the virtual body. Each Actor is reconfigurable, and the interface to control the various processes of the dVS Runtime is common across a number of different platforms (Division, 1996).

The dVS Runtime environment provides facilities to write user-developed applications as well as the ability to create third-party Actors which can be integrated with the dVS Runtime. Additionally, Division provides a shared-database communication scheme which is available to third-party Actors. The interprocess communications (IPC) is based on semaphores and shared memory of the native operating system. Consequently, Division's IPC is high-speed and can be used for periodic or asynchronous updates. Division also supports networked, collaborative VEs.

dVISE. A Virtual Data Interchange (VDI) database is used as input to Division's interactive VE authoring tool, dVISE. The VDI script is an ASCII database which is used to describe objects in the VE as well as events that occur as a result of user or object interactions. Objects can be inherited from VDI libraries and augmented with additional behaviors. The authoring/user environment supports many different 2D and 3D peripheral devices and allows the participant to create VEs interactively. Division also provides the ability to expand dVISE with user-defined events which makes it possible to tailor dVISE to meet the user's unique requirements.

FORCE-FEEDBACK SYSTEM (SensAble Technologies)

The haptics capability of the VETT testbed comes from SensAble Technologies' PHANToM haptic interface and Ghost software development kit (SDK). The Haptics Actor is designed to fit in with the other Actors that make up the dVS Runtime. The design assumes that the definition of the haptic database is external; haptics attributes, defined in the VDI database, are attached to entities in the VE. The Haptic Actors must monitor these entities and reflect their state (position etc.) within the haptic database. The Haptics Actor also monitors and reports the position of the PHANToM input stylus to the dVS Runtime environment (Division, 1997).

SIMULATION SYSTEM (Dynasim AB)

Dymola. Dymola, from Dynasim AB, is an object-oriented software tool for modeling large continuous-time systems and discrete events. The tool allows the modeler to create simple "base" classes that abstract shared physical interfaces between various components in a large system. The base classes are typically used to define what a "connection" is between two or more components (Elmqvist, 1994).

Dymosim. Dymosim is C program text that is generated from the Dymola language description. Additionally, Dynasim AB provides utilities to create a real-time version of Dymosim that contains fixed-step size integration routines, a shared-memory API for control, and access to all model parameters, inputs, outputs, and state variables via shared-memory. Configuration files are used to select the integration scheme, initialize variables, and determine the duration of the simulation for non real-time applications. Additionally, any number of processes can be attached to shared memory. This is useful for displaying the results of the simulation to the participant in the VE or for data collection.

VISUAL SYSTEM (Paradigm Simulation Inc.)

Vega. In order to provide a realistic environment to conduct ship handling experiments, it was necessary to add marine effects to the testbed capability. Instead of designing a new visual Actor from scratch, it was decided to augment Division's existing visual Actor with the marine special effects of Vega Marine provided by Paradigm Simulation. Vega application definition files (ADF) are used to configure the entire Vega system by incrementally loading ADFs based on environment variables. Once the Vega system is configured, all system definitions are resolved to ensure that the loaded configuration is valid.
VR-Link. Although DIS is not required in current testbed applications, a DIS interface is now possible via the DIS option of Vega. Vega DIS is built on top of Mäk Technologies VR-Link. Details as to the full implementation are still being considered.

SPEECH RECOGNITION (Entropic Research)

HAPI/HTK. Entropic Research's HAPI speech recognition system was added to the testbed as a needed capability to command various controls of an application using voice. HAPI provides all the features of a modern speech recognizer including acoustic speech models based on Hidden Markov Models, pronunciation dictionary, language models, and GUI-based tools for constructing application grammars (Odell,, Ollason, Valtchev, & Whitehouse, 1997)

The Speech Recognition Actor is classed as an Input Actor, taking as input vocal utterances and converting them into sequences of key-press events that are reported using the conventional dVS input stream. This input stream is monitored by other Actors in the dVS Runtime, including dVISE. Currently, only tagged ASCII characters are used as input to dVISE from the Speech Actor. Future plans for natural language processing are being considered.

DATA COLLECTION/RECORD/REPLAY

Data Collection. The Data Collection Actor is designed as a configurable Actor with interfaces to the dVS runtime environment and the Dymosim shared-memory arena. Data collection is broken out into information that is periodic and aperiodic. Periodic data comes from two different sources: 1) the simulation, and 2) the participant's body movements. Aperiodic data is generated primarily from the participant's interactions in the VE via dVISE.

Record/Replay. As a means of data elicitation and subject feedback, a Record/Replay Actor is currently under development. The ability to record a session with playback is complete. Future plans include first or third person review, fast forward/reverse, pause, and the ability to step into the simulation during replay.

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ASSESSMENT AND EXPERIMENTAL APPLICATIONS OF VIRTUAL REALITY TECHNOLOGY

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NOTES ON DAY 3 OF THE RSG28 WORKSHOP

INTRODUCTION

The subject of Day 3 of the December 1997 Workshop of the RSG 28 was Assessment Methods and Military Applications. This subject followed logically on the subjects discussed during the previous two days of the workshop (military requirements on Day 1 and human factors issues on Day 2).

During the introduction of Day 3 the chairman outlined

- That a thorough task or training analysis is required to identify the potential use of VR by the military,
- That a comparison of alternatives (desktop/simulators/VR) was required to get optimal solutions with respect to cost/benefits,
- That a thorough evaluation was required for quantifying the benefits and success of applications.

Day 3 included these issues. In particular, the speakers talked about which military requirements were met, how VR was applied, which human factors were involved, what evaluation results they obtained and what future plans they had. Also, assessment methods were presented: what was being assessed and how, strength and weaknesses and potential uses.

The program also included telepresence applications (e.g., remote operations) which show interesting similarities with VR except that the environment is not computer simulated but camera generated.

PROGRAM

Mr. P. Dumanior (US) :
Dismounted Warrior Network
Dr. D. Ryan-Jones (US):
Explosive Ordnance Disposal
Maj. B. Taylor (UK):
Remote Controlled Vehicle "Wheelbarrow"
Dr. J. Leddo (US):
An Intelligent Tutoring Simulation For Military Operations In Urban Terrain
Dr. N. Cislo (FR):
Telepresence And Intervention Robotics
Dr. L. Magee (CAN):
Exploratory Use Of VR Technologies For Training Helicopter Deck-Landing Skills
Dr. B. Loftin (US):
Shared VE For Collective Training
Dr. P. Hue (FR):
French Military Applications Of VR
Dr. R. Hays (US):
Formative Evaluations Of The VESUB Technology

Mr. F. Kuijper (NL):
HMD-Based VE For Military Training - Two Cases

Some general conclusions can be drawn from the presentations listed below.

REASONS FOR USING VE

Some important reasons for using HMD-based virtual environments and not other simulation techniques (e.g. large screens displays) are

- The need for 360 degrees around viewing, realism and time pressure (Dumanior) and
- The need to continuously change viewpoints (walk around objects), or to do 3D manipulations (Ryan Jones)

SHOWN BENEFITS OF VE

- Working with equipment can be trained in time before delivery of the equipment (Taylor)
- Significant reduction of equipment cost (Taylor)
- More efficient training because in VE a higher density of relevant events can be simulated than can occur in the real world. Furthermore, in VE training is more flexible and can be focused on specific training needs (Magee)
- Collective distributed team training can be realized in a cheaper and more effective way via shared VE (Loftin) than in real environments (Loftin)

PROBLEMS ENCOUNTERED

General problems mentioned most were:

- Accuracy, calibration and stability of tracking devices (Dumanior)
- A too low resolution and too small field of view in HMD applications (Dumanior)
- The fact that verbal and non-verbal communication between users of a shared VE is poorly facilitated (Loftin)

- Conservatism of potential users (Ryan-Jones)
- Security issues, for example when classified manuals have to be digitized and integrated in the VE (Ryan-Jones)
- The long time it takes to model VE (Ryan-Jones)
- Lack of intelligent "avatar behavior" in VE (Magee)
- Lack of configurable scenario generators (Taylor)
- Lack of natural intuitiveness for using hands-free locomotion interfaces

ISSUES NOT ADDRESSED ON DAY 3

The spectrum of applications presented was limited to Army and Navy applications and did not include Air Force applications such a VE or augmented reality for supporting pilots during complex navigation tasks.

The applications discussed mainly focused on training, whereas VE has also much potential as a new interface for operating tasks such as damage control and command and control.

DISMOUNTED WARRIOR NETWORK EXPERIMENTS

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INTRODUCTION

The Dismounted Warrior Network (DWN) project began in November 1995 with the publication of the STRICOM Individual Combatant Simulation Technology Transfer Plan [1]. Sponsored by the US Army Infantry Center (USAIC) and the US Marine Corps (USMC), the purpose of the first phase of DWN was to provide a means of understanding dismounted infantry simulation requirements. A series of experiments and exercises were planned, to include an assessment of the cost and benefits associated with the technologies to immerse the individual combatant within the virtual battlefield. One of the most important products of DWN is a Simulation Task Analysis, which was developed to support simulation for IC in the Training, Exercises, and Military Operations (TEMO), Advanced Concepts and Requirements (ACR), and Research, Development and Acquisition (RDA) domains. A preliminary technology analysis was conducted to assess and select current representative IC simulation technologies for inclusion in the DWN experiments and exercises.

APPROACH

DWN is a STRICOM-led project executed under an Advanced Distributed Simulation Technology (ADST) II delivery order, with Lockheed Martin Corporation as the prime contractor. In January 1996, STRICOM assembled a team of technical experts from Government and industry to evaluate the current state of the art in IC simulation. The team visited several technology providers and assessed the maturity of the simulations as they supported the DWN needs.

As the focus for the DWN experiments was on virtual simulation, the systems were required to be real-time, man-in-the-loop, and DIS compatible so that several platforms could be networked. Among the system components reviewed and assessed were: body movement tracking, visual animation of human figures, directional sound, surrogate weapon systems, locomotion simulation, human gesture recognition, natural language processing, SAF capability and analytic modeling. Several contractors proposed innovative solutions for inserting the individual into the synthetic environment. However, based on budget and time constraints, STRICOM preferred that the systems be developed and actively funded. The technologies selected were grouped into four Virtual Individual Combatant Simulators (VIC), each capable of providing a single individual the ability to interact within the virtual battlefield with other VIC and platforms in a DIS exercise.

In addition to the VICs, a Dismounted Infantry (DI) Semi-Autonomous Forces (SAF) capability was required to support more than a fireteam level battle (i.e. to round out the squad/platoon with computer generated forces). The DWN team investigated a number of different SAF systems that model DI. Among the technical capabilities reviewed during the SAF evaluations were: the SAF development language, platform on which the SAF runs, support of DIS protocols, human figure animation, ModSAF basis, voice recognition, gesture recognition, and interaction with 3D terrain.

Following the technology assessments and selection, the DWN delivery order was awarded in June 1996. Several Technical Interchange Meetings were held among the Integrated Product Team (IPT) to design the experiments and exercises. Following a brief integration period, the engineering experiments were conducted during a three-week period in April-May 1997 at the Orlando, FL Lockheed Martin facility. The VICs were relocated and the user exercises were conducted during a three-week period in May-June 1997 at the Land Warrior Test Bed, Ft. Benning, GA.

OBJECTIVES

Simulation Task Analysis. Among the key objectives of the DWN project is to develop a Requirements Document for US Army and USMC IC simulation. The DWN experiments and exercises were conducted to provide a proof of concept for the technologies that enable the individual to interact within the virtual battlefield. The DWN Simulation Task

Paper presented at the RTO HFM Workshop on "The Capability of Virtual Reality to Meet Military Requirements", held in Orlando, USA, 5-9 December 1997, and published in RTO MP-54.

Analysis was developed to assist the Army and USMC soldiers in defining the requirements for IC simulation in the ACR, RDA and TEMO domains. A Functional Definition Process was developed, based on the Army's Close Combat Tactical Trainer (CCTT) Program, with changes necessary for the ACR and RDA domains. Linkage was provided to existing Army and USMC doctrine and tactics. Individual to squad, squad to platoon, and platoon to company organization level tasks were analyzed for the domains.

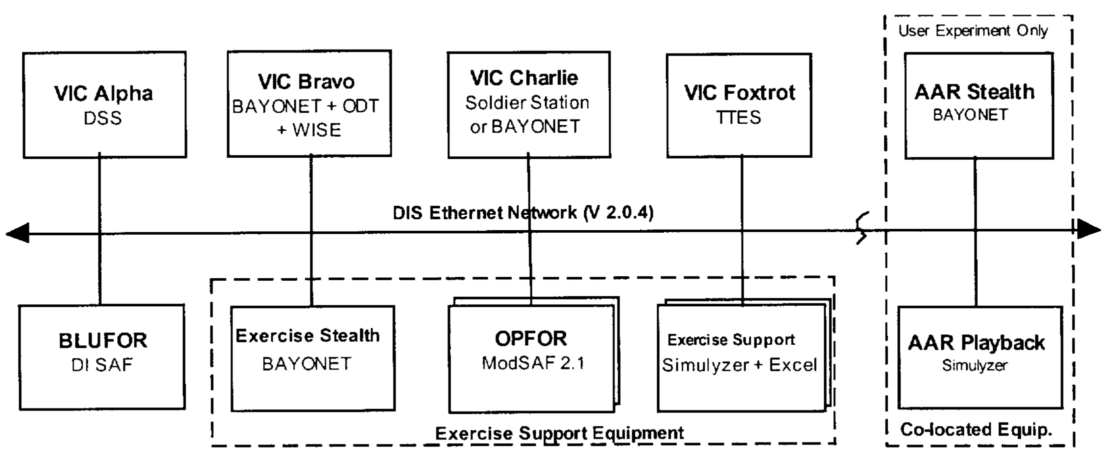
An extensive series of documents were systematically developed as part of the Simulation Task Analysis and became the basis for the DWN Requirements Document. This documentation provides traceablility back to doctrine. A relational database was developed to allow direct Validation, Verification and Accreditation functionality. The documents include the following: Functional Definition Process, ACR/RDA Functional Definition, TEMO Functional Definition, ACR/RDA Functional Fidelity, TEMO Functional Fidelity and Requirements Document. The information can be viewed and downloaded by accessing the DWN home page at http://www.rciorl.com./htms/warrior.htm. The intent of the Requirements Document is to form the basis for follow-on virtual IC simulations and simulators required by the Army and USMC.

DoD Defense Technology Objective (DTO). DWN directly supports DTO IS.40.01, Individual Combatant and Small Unit Operations (IC/SUO) Simulations in the Synthetic Environment. This joint DTO is led by the STRICOM Engineering Directorate. Among the objectives is to develop and demonstrate technologies for creating real-time simulations to immerse the individual soldier and allow for interaction in the synthetic environment. The products that will evolve within the DTO include simulations which are High Level Architecture (HLA) compliant and that support low cost solutions for mission rehearsal, materiel development and training of individual soldiers and marines. There is also potential application of these technologies to training and rehearsal for the FBI and law enforcement communities. DWN and its results will form the basis of the virtual simulation capabilities for the IC/SUO DTO.

EXPERIMENTS AND EXERCISES

Technologies

Four VICs and DI SAF were integrated and evaluated on two digital terrain databases during the DWN engineering experiments and user exercises. As mentioned above, these technologies were chosen based on maturity, capability, availability and their contribution to form a representative and complementary sample of existing technical approaches. Figure 1 provides a System Block Diagram for DWN.



Notes:
(1) DIS Compatible virtual radios supplied with each system for operator coordination, but connected together on a separate ethernet network ("admin net");
(2) Separate wireless radio net between soldiers using the four VIC's and the Exercise Stealth ("tactical net");
(3) Second ModSAF and second Simulyzer provided as back-up and to provide additional PVD for Exercise Director and Battlemaster

Figure 1. DWN Block Diagram

As shown, the system consisted of four VICs, a BLUFOR station comprised of DI SAF, Exercise Support equipment, and an After Action Review (AAR) capability. All systems were connected via an ethernet network and communicated

with each other via DIS 2.0.4 PDUs. A wireless radio was provided for communications between the soldiers on the operating VICs.
The four VICs provided a wide variety of techniques for accomplishing the basic functions of locomotion, display, and weapon aiming as shown in Table 1.

Function	VIC Alpha	VIC Bravo	VIC Charlie	VIC Foxtrot
Locomotion	Human Joystick	ODT	Joystick	Foot Pedal + Head Orientation
Visual Display	Wireless HMD	4 Projection Screens (WISE)	Desktop Monitor	Single Projection Screen
Body Motion Capture	Video	Magnetic	N/A	Magnetic
Weapon Tracking	Video	Magnetic	N/A	Acoustic
Weapon Aiming	Video thru HMD	Video thru IHAS	Video crosshairs on CRT	Rifle sight on rear projection screen
Directional Sound	SOUNDSTORM 3d	SOUNDSTORM 3d	Yes	Yes
Human Animation	Biomechanics	DI-Guy	JackML	DI-Guy

Table 1. VICs Comparison Matrix

VIC Alpha is the Dismounted Soldier Simulation (DSS) system developed by Veda, Inc. under a STRICOM Broad Agency Announcement contract [2], [3], [4]. Unique technologies utilized by this system are the optical (camera) based full-body motion capture system, the use of a wireless head-mounted display (HMD) and the 'human joystick' paradigm for locomotion. VIC Alpha is the only completely untethered DWN system that allows the soldier to freely maneuver in a pre-defined space.

VIC Bravo is a combined system consisting of Virtual Space Devices, Inc. (VSD) Omni-Directional Treadmill (ODT) mobility platform combined with Reality By Design's (RBD) Bayonet visual simulation system. Bayonet is based on NPSNET-IV from the Naval Postgraduate School with additional RBD enhancements, extensions and optimizations specifically for IC operations [5], [6], [7]. Unique technologies presented by this system include an omni-directional, force-feedback mobility platform allowing full 360-degree operation. The Bayonet system presents a 270 degree field-of-view visual display using a Walk In Synthetic Environment (WISE), combined with a monocular monochrome HMD simulating the video camera from the Land Warrior (LW) system. Bayonet utilizes magnetic based tracking for weapon aiming.

VIC Charlie is the TRAC-WSMR Soldier Station [8], [9]. Soldier Station is a combined virtual/constructive simulation solution focused on analytic modeling and evaluation. Unique technologies include the use of a joystick and touchscreen user interface, with a computer monitor display. Soldier Station uses validated constructive algorithms from Janus combined with an enhanced version of NPSNET-IV for visuals, networking and the user interface. The fully functional Soldier Station was used during the user exercises only.

VIC Foxtrot is the USMC Team Tactical Engagement Simulator (TTES) developed at the Naval Air Warfare Center (NAWC-TSD). TTES presents a high-resolution virtual image via a large rear-projection screen. Locomotion velocity is controlled using a pressure sensitive foot pedal. The user's head is tracked with a magnetic sensor and is used to control steering through the environment. A de-milled rifle is used for aiming and firing and is tracked using an acoustic sensor.

Based on the data collected and analyzed during the technology assessment, a DI-oriented SAF system did not exist with Army behaviors suitable for the DWN experiments. An Army DI SAF capability was therefore developed by SAIC based on the USMC IC SAF, which had supported Leathernet as part of the DARPA STOW program [10]. The USMC IC SAF behaviors were modified to reflect standard Army doctrine and an additional twelve behaviors were added to the original set of maneuvers. The DI SAF will be integrated into ModSAF 4.0.

Two digital terrain databases were selected based on the high fidelity requirements for IC operations. The Range 400 database of 29 Palms, CA was selected based on its dense resolution and open terrain features. The McKenna Military Operations in Urban Terrain (MOUT) database of Ft. Benning, GA was also selected based on its high resolution and representation of a built-up area. Both databases are Government furnished managed by the US Army Topographic Engineering Center (TEC). All VICs used a visual representation of the databases in the industry standard Multigen Flight format. DI SAF used a correlated version 5 Compact Terrain Database (CTDB) format database of the same regions.

ENGINEERING LEVEL EXPERIMENTS

The engineering experiments were conducted at the Lockheed Martin Information Systems facility in Orlando, Florida from 19 April-10 May 1997. The purpose of the experiments was to assess the capabilities of current IC simulation technologies in support of future training, virtual prototyping and evaluation of new weapons systems.
Eight soldiers from Ft. Benning, GA served as subjects for the experiments. Each soldier utilized and experienced all VICs and scenarios. Three days of training and testing per soldier were conducted per VIC. The U.S. Army Research Institute (ARI) collected data and provided an independent evaluation of the experiments. Data was collected by the following means: DIS PDU data logging, Pre- and Post-exercise subject debrief and rating assessments, and videotaping. Measures of performance were specified for each experiment and were augmented by subjective ratings and questionnaires. Data from the experiments was analyzed using Excel and statistical analysis software [11].

A number of IC simulation issues were examined during the experiments. Table 2 provides a summary of the functions, issues, performance measures and tasks for the specific variables tested and analyzed.

Function	Issues	Performance Measures	Tasks
Locomotion	• Time to acquire proficiency • Level of proficiency	• Errors over time (collisions) • Task completion times • Movement rates	• Move through building; maneuver around obstacles
Visual Display	• Lag • Resolution • Object detection/identification • Facilitation of locomotion (Distance estimation)	• Time to detect/identify object • Range at object detection/i.d. • Location of object relative to self/other object locations • Engineering measurements	• Locate and identify vehicles, DI (friendly and foe)
Body Motion Capture	• Accuracy • Lag • Reliability	• Engineering measurements	• No man-in-the-loop component
Weapon Tracking/Aiming	• Sighting Ease • Tracking Accuracy • Lag	• Accuracy of shooting at static and moving targets • Time to engage • Engineering measurements	• Shoot at static and moving targets
Directional Sound	• Object localization	• Speed and accuracy of assessment of object direction and location	• Locating noisy objects in environment
Human Animation	• Lag • Realism	• Engineering measurements • Subjective assessments	• Observe DI figures walking, running, crawling, etc.
Miscellaneous	General Issues: • Comfort, Simulator sickness • Noise, Safety • Immersion	• Engineering measurements • Subjective assessments • Questionnaires	• Observe during execution of all tasks

Table 2. Engineering Experiment Design

The intent of the Engineering Experiments was to compare the various component technologies represented in the four VICs over different tasks. The results were documented in order to be matched against functional fidelity requirements flowing from the simulation task analysis portion of DWN. The results will provide the beginnings of a database that will match existing technologies and capabilities against simulation requirements, and the identification of areas where future technology development is required.

User Level Exercises

The user exercises were conducted from 27 May-13 June 1997 at the USAIC Dismounted Battlespace Battle Lab (DBBL) using the Land Warrior Test Bed (LWTB) facilities, Ft. Benning, Georgia. The purpose of the user exercises was to focus on the system level capabilities of the technologies, whereas the engineering experiments focused on the technology components. The ability of the soldiers to operate on the VICs to support collective and individual dismounted infantry tasks was evaluated.

Two basic scenarios were conducted -- an open terrain attack/defend operation on the Range 400 database and a building clearing operation on the McKenna MOUT database. All operations involved a platoon of friendly forces consisting of the VICs operating as a four-man fireteam, together with a second fireteam of SAF. All friendly entities were commanded by a platoon leader using a joystick-driven version of Bayonet. All operations were simulated under daylight conditions. During each exercise, one of the VICs would serve as the fireteam leader.

The open terrain scenarios involved two basic variations -- an attack on an opposing force (OPFOR) site and the defense of a friendly site against an advancing OPFOR. Minimal cultural features are available on the Range 400 desert database so the soldiers were forced to make the most use of the terrain features for cover and concealment. Standard Army doctrine was used to conduct the operations including the use of bounding overwatch and suppressive fire. The end of an exercise was declared to occur when either all enemy or friendly forces were eliminated.

The MOUT scenarios involved the friendly forces clearing opposing forces from a village. Operations were conducted with enemy placements both inside and outside of the structures. Several scenarios involved an enemy sniper located in multi-story buildings thus requiring the friendly soldiers to enter the structures, advance down narrow hallways and proceed up and down stairways. The sniper was played by a man-in-the-loop using a Bayonet station. The end of an exercise would be declared when all enemy had been eliminated as a threat or the friendly forces were unable to continue due to casualties.

An After Action Review (AAR) was conducted at the conclusion of each exercise, including data logged playback of the scenario. ARI collected anecdotal data during the exercises and subjective data during the AARs.

RESULTS OF DATA ANALYSIS

PDU Data Analysis. DIS PDUs, specifically Entity State, Fire, Detonation, and Collision PDUs, collected at the exercise support station served as source data for the majority of the analyses conducted after the engineering experiments. The experimental tasks were intended to investigate VIC performance in the areas of locomotion, visual system performance, and weapon aiming/shooting accuracy (see Table 2). The results of these tasks are described below.

Locomotion. All VICs were set with identical maximum sustained rates of locomotion. Based on course completion times, Bravo was the slowest VIC because the soldier had to expend real energy to move through the environment. Foxtrot was the fastest of the VICs, but at a cost of significantly more collisions with building structures. Bravo, along with Alpha, had the fewest number of collisions.

Visual System. VICs Charlie and Foxtrot had the highest resolution visual systems, followed by Bravo, with Alpha's HMD providing the lowest resolution of all the VICs. Performance in the target search, recognition, identification, and animation detection tasks generally reflected these differences in resolution. In decreasing order of performance, the VICs ranking for these tasks is Charlie, Foxtrot, Alpha, and Bravo.

Secondary performance measures included target range and azimuth estimation and the detection of target motion. For the estimation tasks, VIC performance rankings were reversed from the primary performance measures (Bravo, Alpha, Foxtrot, Charlie from best to worst). A more spatially constant representation of azimuth heading in Bravo and Alpha is proposed to explain the performance differences in this measure; better range estimation performance is believed to be an artifact of fewer long-range detections. Finally, VIC Alpha and, to a lesser degree, Foxtrot performed worst at target motion detection. It is hypothesized that these head-coupled systems made it more difficult to isolate target motion from self motion.

Weapon Employment. None of the weapon tracking/aiming technology implementations provided an adequate weapon aiming solution. VICs with more natural aiming methods (i.e., Bravo and Foxtrot) were better at target acquisition, but Foxtrot's acoustic sensors proved the least accurate weapon tracking system.

Subjective Data Analysis. ARI researchers collected a variety of subjective data through the administration of questionnaires, by observation, and by soldier interviews. Some of the primary findings include the following:

- Simulator sickness was not a problem for the soldiers using the VICs.
- Task difficulty ratings generally followed the pattern of results found in the PDU data: VICs that performed better were judged easier to use.
- Bravo was ranked as the overall best VIC in supporting tactical realism by soldiers during the user exercises; Foxtrot was generally second in the various ratings
- Coordinating movement among the VICs was considered difficult
- Alpha's ratings were negatively affected by a lack of system reliability
- Charlie had some good features but was generally considered the most unrealistic

Other issues concerning database correlation between the SAF and VICs (and between VIC Charlie and the other VICs), VIC virtual figure identification, extraordinary SAF lethality, and communications difficulties were noted during the user exercises.

Discussion. The experimental results point out the relative strengths and weaknesses of the VICS and DI SAF. Weapon tracking is still problematic – none of the three technologies used provided the required accuracy. The case was made once again for better display resolution and field of view. Locomotion technologies need to provide for rapid transverse of open terrain as well as precise maneuvering inside of buildings. VICs need to appear natural, easy to use, and reliable to gain soldier acceptance. These lessons learned provide the evolutionary forces to shape future VICs and SAF development efforts.

FUTURE EFFORTS

Follow On Enhancements

Based on the preliminary technology assessment and observations made during the experiments and exercises, several components or technologies are missing that are needed for realistic dismounted infantry operations. Some clear deficiencies have been identified and others have been revealed by the analysis of the experimental data.
None of the VICs utilized in DWN have the ability for the soldier to command and control SAF directly using voice or gestures. All SAF operations must be controlled with an additional man-in-the-loop 'battle master' to issue instructions and orders to the SAF entities. An intuitive and direct interface to allow command of SAF by a real soldier-in-the-loop is desired to enhance the reality of scenarios.

Communication between the soldiers on the VICs was accommodated by a wireless radio technology. While this approach did allow the soldiers to talk, it simulated a basic radio capability that individual soldiers do not have today in the field. In addition, the soldiers were not able to sense distance or location to the originator of the transmission as they would in the real world. As soldiers become more equipped in the future, the capability is needed to more accurately simulate communications between individual soldiers and link the soldiers with higher command, including digital messaging.

As noted, individual combatants need to perform several activities that are not currently fully supported by any of the current VICs. Some of these activities include: throwing a grenade, setting and detonating explosive charges to gain entrance to a building, scaling walls and rappelling down ropes. These tasks and others are identified by the simulation task analysis and warrant further research and development. STRICOM, together with other Government and industry partners, is continuing to identify and work toward solutions for individual combatant RDA, ACR and TEMO simulation requirements for the future.

SUMMARY

The STRICOM Dismounted Warrior Network program is designed to identify the requirements and capabilities related to man-in-the-loop, networked systems to support individual combatant simulation. The simulation task analysis phase is oriented toward defining a set of validated requirements and functional fidelity needed for soldiers using technology to support the RDA, ACR and TEMO domains. The engineering experiments and user exercises were an attempt to gather relevant data to determine which technologies and systems are useful today and identify areas where significant future work is needed. Several representative technologies were integrated to provide technical insight regarding issues concerning IC simulation. Based on analysis of the data collected, the US Army is focusing future efforts on the identified technologies that require enhancements to meet realistic IC simulation capabilities.

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APPLICATION OF VIRTUAL ENVIRONMENT (VE) TECHNOLOGY FOR EXPLOSIVE ORDNANCE DISPOSAL (EOD) TRAINING

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The primary job of an EOD technician is to deal with unexploded ordnance. There are over 20,000 different technical publications covering items in the ordnance inventory. The large number and variety of ordnance effectively precludes memorizing the identifying characteristics and render-safe and disposal procedures for more than a few common items. Although ordnance can be blown up in place, each technician must be trained to disarm and dispose of ordnance as if the conditions do not allow it to be blown up in place.

The technician's job involves several distinct steps. First, the technician must conduct a site reconnaissance to determine the tactical situation. This may be performed personally or with a remotely operated vehicle (ROV). Next, the technician attempts to identify the unexploded ordnance from visible features. This can be very difficult if the ordnance is damaged or partially buried in the ground. Identification can also be difficult if the ordnance is an uncommon inventory item, or when it is a new model of an existing item. As a result of these factors, there may be a great deal of uncertainty about the identity of the ordnance.

But, once the ordnance is tentatively identified, the real work begins. The technician must match the ordnance with the Series 60 technical manual that contains the render-safe and disposal procedures. The technician will then review the associated Series 60 publication, and memorize the render-safe procedures. Because manuals are in a traditional text with graphics format, it is not possible to practice EOD render-safe procedures before they are performed. This makes the job more dangerous than it should be. Other than technical publications, there are few aids available to the technician for procedural review and practice.

Once the render-safe and disposal procedures are memorized, the technician must select the tools required to perform the procedures, and then actually disarm and dispose of the ordnance. The tools of the trade are quite varied, and part of evaluation in training is the correct selection of the tools. It can reasonably be presumed that if the technician develops a good mental model of the disarming and disposal procedures, the work will proceed in a safe and uneventful manner.

Procedural skills are believed to be highly perishable. Frequent practice and review is normally required to reach and maintain acceptable levels of performance on complex procedural tasks. But again, the very nature of the ordnance universe does not support traditional training techniques. EOD tasks involve coordinated use of sensory, cognitive, psychomotor, and memory faculties, so one would expect that the EOD training environment would be very realistic, and the standard for realism is the ordnance itself. Ordnance disposal is analogous to just-in-time training. That is, a technician trains on a procedure just before the procedure is to actually be performed.

In the school setting, training may be accomplished by the use of live and inert ordnance, or with mock-ups. But the use of live or inert ordnance may not be the best way to train for correct identification, disassembly methods, or render-safe procedures. It is inherently unsafe to use live ordnance for training, and realistic practice usually involves costly supervision and strict safety procedures. Both live and inert ordnance may be very expensive, and may be damaged or destroyed in the process of completing the render-safe and disposal procedures. In addition, there may not be sufficient ordnance available so each student will have his or her own example to practice on. The use of mock-ups can also be a problem because of low-fidelity and functionality problems.

The work discussed here incorporates interactive graphical models and animated demonstrations into the technical training material. Prior research has suggested that realistic 3D representations are vital in learning the spatial and procedural relationships underlying device construction and operation, and may enhance learning of the spatial characteristics of ordnance, giving students the opportunity to encounter, resolve, and practice multiple options for disposing of live ordnance.

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VE technology seems to be well-suited for training in this context. Ordnance is clearly three-dimensional. Technicians must walk around ordnance, and in certain cases hold and rotate ordnance in their hands. There are great changes in scale from the technician's perspective during the procedures. In addition, there are dynamic interactions between the technician and the ordnance that frequently involves the use of tools required to safely disarm and dispose of the ordnance.

In spite of the promise of better training from the use of VE technology, there are problems associated with implementation of advanced computer technology in the military school environment. Perhaps the greatest problem is the reluctance of the schools to change the current system. The system is based upon traditional lecture supplemented by demonstration and practical exercise. The current system works well but new technology probably works just as well and requires fewer instructors and administrators.

A secondary issue is the cost of creating the courseware to be implemented at the school. Much of the cost is related to the creation of the models used in courseware. Although engineering drawings of ordnance already exist, CAD/CAM models are virtually nonexistent. So, much of the cost of a virtual training systems is the expense of building the 3D interactive models. One technology competing with VE is animation, and embedded animation can also be used to train or review ordnance render-safe procedures with a much lower development cost than a fully interactive virtual model.

In the research described here, VE technology was used in a module intended to train students to perform the render-safe procedure for a single ordnance item. The objective of this project was to demonstrate that EOD procedures could be taught by a virtual ordnance model. The specific technology used in this project was determined by the funding level, model development costs, command desires, and the potential for implementation. Our strategy was to select off-the-shelf hardware and software as much as possible to meet the stated objective of the project.

The ordnance selected as the prototype for the project was the SUU-25 flare dispenser. This is a device by which flares that are intended to illuminate a battlefield are dropped from an aircraft. The dispenser may contain live flares that are in themselves explosive, as well as mechanisms to force them out of the dispenser. The dispenser is made safe by a sequence of actions that involves cutting wires, removing ejection cartridges, removing an access door, inserting a shorting pin, and removing any live flares. This particular piece of ordnance is the family prototype used at the EOD school. The dispenser is inert and attached to a helicopter in that environment. Since the device is inert, students are trained and tested by describing the render-safe and disposal procedures.

Command and fiscal restraints required that training be performed on a personal computer in the form of a traditional computer-based training module. Authorware Pro was selected as the instructional development software, 3D Studio for the modeling software, and World Toolkit for Windows as the virtual environment software. At the time of initial development, a 133 MHz Pentium processor was state-of-the-art, and the fidelity of the model and its characteristics was reduced to accommodate these restrictions. The actual flare dispenser is cylindrical but the model is 12-sided to restrict the number of polygons to about 20,000. In addition, the model does not rotate continuously but in 10 degree steps to speed up the response on the screen. The slow response of the model during rotation was perceived as a problem by the development team but not by the users at the EOD School. As personal computer technology advances, the virtual model will become more responsive or the level of fidelity can be increased with the same response time.

When the model was first tested at the EOD School the instructors suggested other changes to the level of fidelity. For example, screws on an access panel had to be removed one by one before the panel could be opened. The instructors felt this was a waste of time, and they suggested that after the removal of just one screw the door should disappear. This principal was applied to other aspects of the render-safe procedure. The unintended side effect was a noticeable change in the perceived fidelity of the model. But, the change was necessary to get the support of the instructors.

One unique feature of the user interface is the tool kit. Every ordnance procedure requires the use of tools, and testing usually involves the selection of the correct tools for the procedure. The tools required to perform the procedure in our module are shown on the screen as icons. The user must select the correct tool to perform a step, and the cursor changes to the icon of the tool. If the wrong tool is selected, the step cannot be performed. During training, selection of the correct tool is guided by the courseware. During testing, the user must select the tool to be used at that step. Selection of the wrong tool or performing a step out of sequence is noted as an error.

The virtual model is embedded in the instructional software by design, and cannot be called outside of the instructional module. The purpose of this restriction is to comply with the instructional philosophy of the EOD School. At the school,

most procedures are taught by demonstration and practical exercise, and free play is frowned upon. In fact, it is very dangerous in the real world to violate the stated procedures. Safety considerations permeate all aspects of instruction at the School. An alternate implementation suggested by the instructors is to incorporate the model into an instructor-controlled demonstration of procedures.

The training module is organized around seven lessons. The virtual model is used in only two of those lessons, one for step-by-step training and the other for testing. The time required to complete the entire module is about forty minutes. However, only ten minutes are allocated at the School for training the entire family of this type of ordnance, and it immediately became obvious that the module would never be implemented in the present form. But, students are required to perform two hours of study on their own each evening, so this may be the best mechanism for formal testing. It is clear from our pilot test that the virtual model is as good as lecture and demonstration, but a transfer of training experiment is required to demonstrate that it is effective and is without negative transfer.

In summary, we believe that virtual worlds will have an important role to play in individual training. The fact that they seem to work as well as traditional instructional methods should encourage us to build more applications. But practical consideration may severely restrict the form of the implementation, and consequently the conclusive evidence that we need to convince others to build more models. In addition, until the cost of building high fidelity applications drops dramatically, it may be difficult to find users willing to take our models and implement them in a training context.

REMOTE CONTROLLED VEHICLE "WHEELBARROW"

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INTRODUCTION

The Army School of Ammunition in Warwickshire, England is the United Kingdom's premier IEDD training establishment. We have been training IEDD operators since about 1922 and most recently our efforts have been centred on the training of individuals for Northern Ireland operations. In addition we also train students from many countries around the world, principally in EOD matters, but also in conventional Land Service Ammunition, which is our main task in the Field Army.

We are currently using and developing two computer-based training systems in the IEDD field. The two systems are:

- RCV Wheelbarrow MK8B Control Trainer System
- IEDD Threat Assessment Trainer

WHEELBARROW MK8B CONTROL TRAINER SYSTEM

Introduction

In 1993 the United Kingdom's prime remote controlled EOD vehicle, *Wheelbarrow* was subjected to a mid-life improvement (MLI). The aim of the MLI was to extend the in-service life of the Wheelbarrow through to the year 2000 whilst development on its replacement took place. This upgrade programme resulted in the complete overhaul of the Wheelbarrow and the introduction of modern electronics technology. Whilst the general appearance of the vehicle did not change its functionality changed considerably. One aspect that did change was the *Hand Controller*. The previous system had been a fairly straightforward unit that was easily adapted to by operators and required very little familiarisation before they became proficient in its use. The replacement was, however, a much more complex system and with each new RCV costing in the region of £100k. In addition, there was a dedicated training requirement for the Hand Controller alone, before we could expose operators to the main vehicle. Of greater importance was the initial timeframe in which the changeover from MK8 to MK8B had to take place. Operational units therefore needed conversion training before they received the new vehicle. Special courses were designed to manage this turbulent period and, over a 6-month period, all IEDD operators from all 3 services in the United Kingdom were converted using this Control Trainer System at the Army School of Ammunition. Anite Systems Ltd. designed the system, initially for the wheelbarrow MK8+, which is an export model.

System Description And Operation

The system was designed primarily to enable operators to become familiar with the functionality of the Hand Controller. To do this we have four control work stations. Each station comprises a standard desktop PC with P75 processor, a 15" monitor, keyboard, mouse and joystick. A standard hand control unit attaches to the processor via an interface box. The software provides 3 separate, but selectable 2D VR environments in which to train. In each training scene a graphical representation of the Wheelbarrow is produced which responds to commands from the Hand Controller with the ability to 'fire' standard IEDD weapons at simulated targets in the same way as the real vehicle. The 'F' keys on the keyboard in conjunction with the joystick allow the operator to move around the scene and also to obtain the classic 'through the camera' view he would get with the Wheelbarrow. The joystick control is independent of the Hand Controller and has no effect on the movement of the vehicle. In each scene there are a number of configuration facilities to add a challenge and variety to the training task. These are:

Street Scene
- 3 incident control point positions

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- 4 IED types (attaché case, petrol bomb, package and car)
- 3 pre-set IED locations (telephone box, under car and car trunk)
- Manual IED positioning
- 3 drive camera positions

House Scene

- 3 drive camera positions
- 3 IED types (petrol can, bottle and attaché case)
- 5 IED locations (lounge, study, kitchen, bathroom, bedroom)
- Manual IED positioning
- 3 lounge layouts
- Manual furniture positioning
- Door set-up

The Test Track adds a competitive edge to the system and comprises an obstacle course designed to test the operator's control of the vehicle. The obstacles include:

- Railway track
- Stairs
- Uneven roadway
- Steep slopes
- Narrow corridors
- Traffic cones

This is a timed task and a clock begins when the Wheelbarrow crosses the start line. If he should hit a cone it adds 30 seconds to the time. He can not drive through walls to take short cuts!

Benefits To Date

This was the first computer based training system we had into service before the main hardware. There have been a number of obvious advantages so far:

(1) It enabled the MK8B to enter service in a timely and efficient manner with personnel already trained in its use.

(2) It is now a fully established training system, which we use for all new operators who come on courses. It allows repetitive training in a controlled and comfortable environment without the need for heavy instructor commitment, equipment support or a training area.

(3) It has significantly reduced the repair bill to the vehicle fleet.

Future Development

Experience with the Control Trainer System has recognised its limitations. For what it was designed to do it does it very well. There are, however, a number of potential improvements to the system that we have discussed with Anite.

- Improved graphical environment
- A configurable scene generator
- A scenario generator
- The ability to use the full range of IEDD weaponry
- A faults generator

These modifications would provide a much greater variety of more realistic situations and give students a more flexible and testing training system. Ultimately our aspiration is to make this part of a family of a team training system. The prototype system for the ANDROS RCV has many parallels in its concept. There is certainly scope for an exchange of ideas.

IEDD THREAT ASSESSMENT TRAINER

The second computer based training system is the IEDD threat assessment trainer. This is currently a concept demonstrator developed by Westland System Assessment Ltd. in conjunction with Centre for Human Sciences and, unlike the RCV Trainer, concentrates on the 'soft skills' of the IEDD operator.

In any IEDD situation the critical time is generally considered to be the first 10 minutes after arrival at the scene. In a very short space of time the operator must be briefed, establish the safety of the ICP, obtain information through questioning, make an initial assessment of the threat and devise his initial EOD plan and response.

This is no easy task and experience has shown that many operators find this aspect of the task the most difficult to master. We are currently developing a concept demonstrator, which replicates this process and is based on an existing classroom exercise.

System Description And Operation

The current system, which has undergone a number of developments, is based on a desktop multi-medium PC running a P90 processor with 16 MB of RAM and a space mouse. The visualisation software is Superscape Visualiser 4.00 running under MS DOS 6.22. MS-Windows 3.11 is also loaded to run MS-Write for exercise feedback.

The Exercise

On beginning the exercise the student is given the opportunity of working through a tutorial. This is simply designed to teach the student the basic computer skills necessary to use the trainer and an explanation and practice exercise with the virtual world space mouse. All students are required to complete the tutorial at least once before the threat assessment exercise.

On completion of the tutorial the student is presented with a screen which basically sets the scene. He is then given an audio brief that tells him exactly what has happened. The imaginary scenario used is an explosion in Canterbury in southeast England, in which there are a number of casualties. He has been tasked to deal with the problem and arrives at the scene within 15 minutes. As the brief is given, he is presented with a schematic diagram of the scene and once this is completed he is presented with an initial view of the scene from the police control point. His exercise now begins.

To the right and bottom of the screen there are a number of user interaction icons coloured blue when non-active and green once selected. There are also keyboard shortcuts for each icon:

- Schematic map
- Question and Answer
- Vewpoints
- Visualisation
- Decision

The Assessment Session is his final choice. Once he has sufficient information he selects the assessment icon which then questions him on his understanding of the situation. He will answer about 30 questions, most of which only require a mouse click in response. A few will require a typed entry.

On completion of the assessment session, he is presented with a final screen that allows him to walk through the virtual world highlighting important aspects such as cordon positions and security cameras in the area. The second choice is feedback. This displays messages, which will have been triggered by certain selections made in the assessment session, informing where the student has gone wrong or congratulating him on making the correct choices.

Benefits Of An IEDD Threat Assessment Trainer

This aspect of an IEDD task is the most critical. If an operator is able to make an accurate assessment of the problem he is then faced with his render safe plan, which should follow quite logically. His skills with the equipment can only be

perfected by practical training, but we see this as a pre-cursor, in many respects, to his practical training. This interactive demonstrator uses a relatively uncomplicated scenario. There are of course many real situations that have occurred which are far more complex and testing. It follows the methodology of dealing with an IED task taught in the classroom and is a natural extension to this teaching.

FUTURE DEVELOPMENTS

This is only the first hurdle. With an improved graphics environment, a greater selection of scenarios and voice-activated commands instead of keystrokes, we are certain this will become a valuable training tool. It will never replace reality, but it will help develop our professional EOD operators and is another step towards our ultimate team training system.

AN INTELLIGENT TUTORING SIMULATION FOR MILITARY OPERATIONS IN URBAN TERRAIN

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Simulation has played a major role in military training. Distributed Interactive Simulation (DIS) allows multiple trainees to interact in real time on a common training problem. While DIS is a powerful training tool, a trainer is typically required to review trainee performance and make the appropriate teaching and remedial points. As training scales to larger and larger exercises, the trainer will naturally focus on general team performance at the expense of individual training needs. Intelligent tutoring systems (ITSs) have focused on providing instruction on a one-to-one basis. Integrating DIS and ITS technologies offer the opportunity to capitalize on the strengths of both: the ability to conduct large scale team exercises while providing each trainee with personalized instruction. The present paper reports a Phase II Small Business Innovation Research (SBIR) project, sponsored by the U.S. Army Simulation, Training and Instrumentation Command (STRICOM) in which an Intelligent Tutoring Simulation™ was developed to train Army Infantry squad and fire team leaders the skills they need to cooperatively perform military operations in urban terrain (MOUT).

BACKGROUND

Simulation has long played a significant role in military training. Whether live, virtual or constructive, simulation is the primary mechanism by which soldiers receive practical training or conduct analysis to prepare for potential missions that they may be called upon to accomplish.

As technology has improved, emphasis has been placed on creating simulators with higher fidelity and networking simulators to support team problem solving. In the military, this is best exemplified by the creation of distributed interactive simulation (DIS). DIS supports training by allowing large numbers of trainees to work together in order to collaboratively solve a problem as they would in a real setting. This is perhaps the most critical innovation within the field of simulation as virtually all military problem solving exercises are collaborative activities. As technology improves, one can only expect to see a capability to provide even more comprehensive training exercises with greater numbers of participants.

As technology has increasingly enabled training exercises to increasingly approximate realism by means of DIS-based virtual simulations, a subtle tradeoff is being made. On the one hand, the increased realism provides greater transfer of problem solving skills to the real world tasks a soldier will perform. On the other hand, as simulation substitutes for instructor-based training, the learning benefits of having active assessment and feedback by a qualified instructor is sacrificed.

The present paper addresses a project we have worked on that tries to give the training community the best of both worlds: distributed interactive simulations for realistic team training and individualized instruction for each soldier based on his learning needs. To accomplish this, integrated intelligent tutoring system technology has been integrated with simulation technology.

Intelligent tutoring systems (cf., Brna, Ohlsson and Pain, 1993; Greer, 1995) use artificial intelligence to place teaching mechanisms into a training system. An intelligent tutoring system (ITS) is defined by three characteristics: an expert model of how to solve a problem correctly, a model of what the trainee knows that can be compared to the expert model, and a pedagogic model that tells the system how to teach the trainee what an expert knows given what the trainee knows.

Each of these components is missing from typical technology-based simulation environments. For this reason a typical simulator can provide practice but not instruction. The contention of the present paper is by integrating the approaches offered by the ITS and simulation communities, an enhanced paradigm of realistic scenarios, coupled with the instructional benefits of ITS technology can be created. We term this technology "intelligent tutoring simulation".

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In order to create a successful intelligent tutoring simulation environment, several technical hurdles must be overcome. This is so because the strengths of each technology are problematic for the other.

For example, simulation environments typically support open-ended behaviors. A trainee can execute any action allowable within the simulator at any time, regardless of whether or not the action is prudent. An ITS, on the other hand, is trying to assess the student. Because it is much easier for a computer to process well-defined linear event sequences, most ITS work has focused on domains where well-defined linear procedures exist, such as algebra and basic computer programming.

In a simulation environment, there need not be a predetermined "correct" answer to the scenario being trained on. Indeed, in many real world problems, a "correct" answer may not be known. In such cases, the instructor tries to evaluate the quality of solution process rather than the outcome of that process. In a military problem this could include such things as proper use of reserves, establishing supply lines, etc. In the ITS world, the emphasis has been on domains where an objective "right answer" exists (e.g., mathematics) as computers are much better at dealing with well defined problems with computable solutions than they are at dealing with ill-defined problems with no computable solution.

As noted earlier, the heart of DIS is collaborative problem solving. However, the goal of an ITS is to assess and teach each student based on his individual needs. Because it is easier to do this process when only a single student is being trained, ITS researchers have focused on single student ITSs.

The present paper addresses how these technical issues were reconciled so that technology could be developed that supports open-ended team problem solving behaviors while providing each team member with individual instruction. In addition to these technical issues, there were other issues that relate to both the simulation and ITS communities.

One of the major weaknesses in the ITS and simulation fields is that both technologies are costly to develop. They typically require highly skilled professionals to develop. Once developed they tend to be highly inflexible such that they often become quickly outdated and need to be rebuilt from scratch when updated. When such rebuilding occurs, there tends to be little reuse of the previous system's technology in the newer version.

An argument can be made that if intelligent tutoring simulation technology is to have a future, it must be made adaptable and generic enough so that the technology can be constructed cost-effectively, be modifiable and updatable by the user, and have considerable reuse across projects to maximize the value to the user for the dollars invested.

These additional objectives influenced the design of the present technology (which is discussed in the next section). The effectiveness of the present technology was demonstrated by building generic and modifiable technology that was extended as the project progressed and was transferred to another project.

THE INTELLIGENT TUTORING SIMULATION TECHNOLOGY

The present technology was developed in partnership with both the Directorate of Operations and Training (DOT) and the Battle Lab of the Ft. Benning Infantry community. We are particularly grateful to Mr. David Reiss who was our point of contact at Ft. Benning and who provided us with support in the form of subject matter experts and project reviews.

In working with the Infantry community, the Military Operations in Urban Terrain (MOUT) task of clearing a building was identified as a high training priority. A decision was made to focus on leadership training, first at the fire team leader level and then at the squad level.

In both cases, leaders perform two major functions: first, they are responsible for making decisions and directing the actions taken by their respective units; second, they are responsible for correcting mistakes made by members of the unit. Therefore, the training objectives that were established for the present technology had both of these responsibilities in mind.

Part of an ITS is the expert model of how to solve problems in the domain. Additionally, a simulation requires a model for computing events within the domain. Both of these are clearly linked. The simulator needs to record trainee actions to compute how events should unfold in the simulation. The ITS needs to record trainee actions to determine learning needs.

In order to build the domain model and the expert problem solving model, extensive knowledge engineering was conducted with subject matter experts supplied by Ft. Benning. This was supplemented by observing live training exercises at the McKenna MOUT Site at Ft. Benning, conducting role playing exercises at RDC headquarters and by reading published doctrine.

These knowledge models formed the basis of the training technology. The next step was to build the actual system. This was done in phases. In the first year of our two year project, a one person trainer for the fire team leader was built. In the second year of the project, a second, networked trainer for the squad leader was added.

In developing the trainer for the fire team leader, the goal was to create an architecture that would be later scaleable to adding the squad leader. A second goal was for the technology to be as generic as possible so as to be modifiable when necessary and usable with simulators other than the one created for the present project.

In order to meet these objectives, a simulation-based intelligent tutoring system was constructed that had three components. The first was the MOUT simulator that allows a trainee to assume the role of a fire team leader and direct a four man fire team in the task of clearing a building. The floor plan used in the simulator is modeled after a building within the McKenna MOUT site.
The simulator creates virtual (but non-immersive) simulations of the inside of a building. World Toolkit™ was used to create these simulations, which run on a standard Pentium PC.

The trainee assumes the role of the fire team leader and directs his team by means of key strokes. Once the key stroke command is issued, movement is automatic. The fire team carries out the commands issued by the trainee, regardless of whether they are "correct". Occasionally, for pedagogic purposes, a fire team member carries out a procedure incorrectly. At this point the trainee has the opportunity to correct the mistake, again using keyboard commands. If the trainee does make the correction, the mistake is not repeated. If s/he does not, then the system continues to cause the fire team member to repeat the mistake.

The second component of the system is the intelligent tutor. The intelligent tutor is responsible for assessing the trainee actions in the simulator, determining whether corrective instruction is needed and directing the simulator to provide such instruction when necessary.

As stated earlier, an intelligent tutoring system is comprised of three components: an expert problem solving model, a student model and a pedagogic model. The logic for how these components were constructed is based on the project objectives. First, one of the major challenges to integrating ITS technology with simulation technology is to allow the ITS to support the open-ended behaviors and ill-structured problems found in many simulation environments. Second, it is desirable to have generic technology that is, in principle, reusable for other training applications and not tied to the specific simulator or set of scenarios that simulator might run.

In order to accomplish these objectives, two innovations were made to the typical expert model found in many ITSs. First, in order to handle the rich MOUT problem solving domain and allow more open-ended behaviors, a richer knowledge representation framework than is typically found in many production rule-based expert systems was used. This knowledge model framework was based on previous empirical research (Leddo, Cohen, O'Connor, Bresnick, & Mann, 1990) on how experts solve problems.
This research shows that experts use a variety of problem solving approaches that are richer than a simple production rule or other single formalism process. As a result, an Integrated Knowledge Structure (or INKS) framework was created that blends scripts, production rules, semantic knowledge and mental models into a single formalism. INKS allows an expert model to process known problem solving sequences as a production rule system would, but also allows a system to use a mental model to reason from first principles given the semantic information available in a situation.

For example, when a fire team moves down a hallway and approaches a door, there is a fairly routinized procedure for stacking, breaching the door and entering the room. In cases where multiple doors are present a decision must be made as to which room to clear first. In such cases, at least two decision making processes are possible. The first is to "hardcode" every possible permutation of how many doors there are, whether they are marked or unmarked (indicating that they are already cleared) and whether the doors are open or unopened (indicating a potential threat as an open door constitutes a potential line of fire from enemies within the room). The expert system could literally evaluate each of the antecedent conditions to determine which rule to fire and in doing so, which room to clear.

An alternative approach, which the INKS expert model allows is to reason from first principles. To accomplish this, the INKS knows about the goal of preserving the safety of the fire team. It knows that being in an enemy line of fire constitutes a safety threat. Therefore, when confronted with multiple rooms, the INKS can evaluate each room to determine which constitutes the greatest safety threat and then decide to clear that one first. By using this mental model approach to evaluating safety threats, the system is not required to have a preset rule to assess a trainee's decision, but can still make the assessment based on known goals and situational (semantic) features.
Being able to reason from first principles leads into the second objective discussed, namely creating an ITS that is generic. Having mental models that reason from first principles is a step in the right direction as this supports reasoning about general cases rather than hardcoded examples.

This train of thought was continued by building the INKS to be a generalized MOUT expert rather than one that was knowledgeable about the specific simulator, floor plan or scenarios used. This was accomplished by encoding the domain knowledge in generic terms such as moving down types of hallways rather than specific hallways, entering types of rooms rather than specific rooms, etc. By doing so, the system is able to reason about any scenario as long as it can make the determination about what type of situation it is in. This makes the ITS independent of the simulator.

A good analogy is be a human trainer. A human trainer is a generic domain expert. S/he can be brought into any training environment and act as a trainer because s/he knows about the domain and can apply that knowledge to the specifics of the training environment because s/he can get, by observation, the relevant information about what learning objectives are being taught and what scenarios are being used to teach them. Before discussing how the ITS is getting this scenario information, the other two components of the ITS are briefly discussed: the student model and the pedagogic model.

The student model uses the same INKS used in the expert problem solving model. In this way, student actions are compared directly to the expert model and assessed accordingly.

For the pedagogic model, there are many options as there is no "one right way" to teach any subject area. Case-based reasoning was chosen as the pedagogic model for two reasons. First, it lends itself well to the scenario-based instruction that the simulation would use. Second, it supports individualized instruction as the student learning style itself can be treated as a case to which remedial instruction could be matched. In the present system, four forms of remedial instruction are used: showing trainees the consequences of their actions with logical scenario outcomes (e.g., a trainee fails to correct a fire team member action that places the fire team in danger, so the case-based reasoner causes a soldier to be killed by an enemy.); providing trainees with miniature scenarios to practice a faulty skill; providing trainees with an auditory explanation of what they did wrong; and providing trainees with a text-based explanation of what they did wrong. The case-based reasoner (CBR) cycles through these potential forms of remediation until it finds a form by which the trainee does not repeat the mistake being remediated. When this occurs, the CBR infers that it has matched the trainee's learning style.

Having discussed the simulator and the ITS, the third component of the technology is addressed. A generic INKS was created to serve as the expert problem solving model. This INKS operates as a human trainer does, inferring from the events in the simulation what type of scenario is being trained so that it can assess the trainee and determine whether remedial instruction is needed.

In order to accomplish this, real time feedback is needed as to what events are happening in the simulation and what actions are being taken by the trainee. To accomplish this, middleware, which is the third component of our technology, was created.

The middleware has two major components. First, in order to provide the INKS with information regarding events in the simulator, a semantic overlay of the floor plan used in the simulation was created. This semantic overlay contains such information as where the doors are, whether they are open or closed, how many locks and hinges they have, etc. Therefore, as the trainee moves through the simulation, the middleware can continually pass this information to the INKS. In essence the middleware acts as the "eyes and ears" of the INKS so that it can evaluate what type of situation the trainee is in and then use its expert model to determine appropriate actions the trainee should take. When the trainee does take an action, the middleware also passes this information to the INKS so that it can assess the trainee's action against its expert model.

If the trainee's action matches the expert model, then no remediation is provided. If remediation is needed, the CBR generates a requirement. This is passed to the middleware. Here is where the second major component of the

middleware comes in. The middleware also contains information about simulator primitives so that it can cause the simulator to produce necessary remediation. The basic simulation-based ITS architecture is illustrated in Figure 1 below.

In year 2 of the project, the goal was to add the squad leader to the training technology. As was the case in the first year of the project, the first step was to conduct knowledge engineering with domain experts, supplemented by published doctrine to gather the necessary domain knowledge.

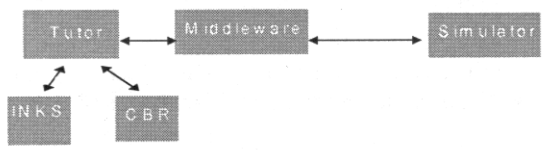

Figure 1. Basic ITS Architecture

However, the goal in year 2 was more than to simply build a second simulation-based ITS. The goal was to create a team trainer. Here, the challenges of creating a distributed problem solving environment while still preserving individualized instruction needed to be addressed. There was an additional technical challenge. The project goal was to create an Intelligent Tutoring Simulation for a squad leader and a fire team leader working together. However, a squad has two fire teams. Therefore, in order to preserve the realism of a two fire team squad, intelligent agent technology was used to play the role of the second fire team (this technology is discussed shortly).

Fortunately, the basic year 1 architecture supported these extensions. First, the MOUT simulator was reused in year 2 (the floor plan was extended to provide a starting hallway for the squad). In order to give the squad leader a separate perspective corresponding to what he would see, a duplicate simulator but with a camera (viewpoint) corresponding to what he would see was created. The squad leader was also provided with a sky view so that he can still watch the actions of the fire team after they disappear into a room. Finally, while the fire teams move as a unit, the squad leader is not tethered to either fire team but moves himself manually using key strokes. However, when he directs the movement of one of his fire teams, their movement is automatic as was the movement of the fire teams when directed by the fire team leader in the year 1 system.

The next step was to build the appropriate ITS for the squad leader. The key step was to build the squad leader expert model. This was done in the same format as the fire team INKS. The CBR was also updated to include the remedial instruction for the squad leader errors. By creating separate tutors for the fire team and squad leaders, an environment was created where each trainee had his own tutor that was responsible for providing him with personalized instruction based on his learning needs.

Once the simulator with the squad leader perspective and the squad leader ITS were created, middleware was constructed to link the two as was done in the fire team leader trainer. This middleware was essentially the same as for the fire team leader. The semantic overlay of the floor plan was identical. The main difference was to be able to pass the squad leader commands in the simulator to the squad leader ITS.

The technology, as described above, constitutes two separate ITSs, even though the second one was constructed far more cheaply than the first. However, the goal was to develop a team training environment so the two systems had to be linked. The linkage was provided through the middleware. Here, in each system, the middleware passed each trainee's simulator commands not only to his own ITS but to the other trainee's middleware. The other middleware then updated the second simulator so that the trainee would view the same events as his partner. To synchronize the two simulators, an internal simulation clock was created. Each event that was passed between the two middlewares was timestamped so that the receiving middleware could update its simulator in a way that would preserve the synchronization between the simulators. The synchronization between simulators is a standard DIS problem and the present paper does not claim to have made any innovation in this area.

The resulting technology was two Pentium PC computers that used a point to point connection. One computer had the squad leader version of the technology, while the other had the fire team leader version. Figure 2 below shows the architecture for the two person intelligent tutoring simulation.

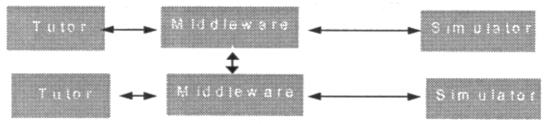

Figure 2. 2 Person Intelligent Tutoring Simulation Architecture

There is one final issue. The present technology is comprised of one squad leader trainer and one fire team leader trainer. However, a full squad has two fire teams. The second fire team was "played" by an intelligent agent.

One of the features of the present ITS technology is the expert problem solving model. This expert problem solving model evaluates the trainee by computing its own solution to the problem and evaluating the trainee against that solution. This feature of the expert model was used in order to create an intelligent agent that would do the same.

Therefore, when the squad leader issued a command that would ordinarily be carried out by the second fire team (fire team B), the expert model would generate an expected action on the part of that fire team. These commands were then automatically carried out. This enabled the agent for fire team B to respond to squad leader commands.

There were cases where the fire team leader would normally issue his own commands. In this case, the expert model would be receiving information, via the middleware, of what events were happening in the simulation. The expert model then computes what the fire team leader should command. In this case, rather than waiting for the trainee to issue a command, the expert model simply issues the command itself.

This ability for the expert model to operate either in assessment mode (when a real trainee is issuing commands) or in agent mode (to issue a command itself) created a unique feature of the technology. Specifically, the intelligent tutoring simulation could not only support two person training, but also single person training in either a fire team or squad leader role. This was accomplished by having a toggle that transferred control of the fire team leader or squad leader from human to computer and back again.

DEMONSTRATION OF THE ROBUSTNESS OF THE TECHNOLOGY

A principal goal of the present project was to create a generic architecture that could be a model for rapid technology construction and software reuse. While a demonstration of this was not part of the original project plan, there was a serendipitous opportunity to provide such a demonstration when RDC received a Phase I Small Business Technology Transfer contract with the Army Research Institute to develop a virtual schoolhouse.

In this project, the goal was to transfer intelligent tutoring simulation technology from the present project and intelligent agent technology from a DARPA-sponsored project to develop team training that could be delivered over a network such as the Internet.
Because higher fidelity simulations require higher bandwidth to be transmitted over a network than lower fidelity ones, a decision was made to use a low fidelity simulation for that project. The entire functionality of the present project was duplicated in the form of a networked, low fidelity, constructive simulation for the ARI project. To accomplish this, both squad and fire team INKS' were reused in their entirety and enhanced them and the middleware was reused in its entirety. This was done by creating a constructive version of the same virtual simulation such that the primitives and semantic overlay provided in the middleware also mapped to the constructive simulation as well as the virtual one.

Essentially, then, the present project technology was completely reused and even enhanced (additional knowledge was added to the INKS in this second project), except for the virtual simulator. However, between the two projects it was demonstrated that the same ITS technology could be applied to two simulators (a constructive and virtual one) without changing either the ITS or the middleware and the same simulator could be applied to two different ITSs (a fire team leader and a squad leader) without changing the simulator (except for the camera angle) or the middleware.
There was a further test of the robustness of the present technology. A scenario editor was created that allowed a user to enter his own scenarios by manipulating certain parameters (e.g., number and location of enemies, their level of training and whether they were combatants, number and location of civilians). As stated earlier, the present technology allows

the computer to run the role of the fire team leader or the squad leader because it processed scenario information in real time and made its own decisions regarding what actions to take.

In this case, numerous demonstrations of our technology were given. Each time, observers were allowed to create their own scenarios and have the expert model run the simulation. There were no cases where the scenario created by an observer "broke" the system or created an unexpected event. This demonstrates the robustness of our expert knowledge model, which is the heart of our technology.

It should be noted again that the virtual schoolhouse system completely duplicated the functionality of the present system. With the addition of the scenario editor, it actually had an additional feature that the present technology does not have. What makes this accomplishment even more noteworthy is that the virtual schoolhouse project was developed using Phase I level resources which are about one-sixth that of a Phase II development effort. This demonstrates how such technology, if carefully constructed, can help leverage future development efforts such that the technology can be replicated and enhanced at considerable savings.

CONCLUSIONS

The present project demonstrates the feasibility of integrating intelligent tutoring system and simulation technologies. It is argued that the value of such integration is by maintaining the team training spirit of today's DIS technology, while providing each participating soldier with the opportunity to receive individualized instruction based on his learning needs.

Further, the present project demonstrated an approach for creating such technology that makes it extendible and reusable at a fraction of the original development costs. This can be considered an important feature as it suggests that such functionality could be added to today's (and tomorrow's) simulator development efforts at a modest cost.

The goal in this project, then, has been to demonstrate the enhancements that could be made to DIS technology by integrating ITS technology and that these enhancements could be done in a cost-effective manner. By achieving these goals, it is hoped that a paradigm shift can be effected in the way simulation-based training is conducted. The authors' vision is that future training technology will be a marriage of simulation and intelligent tutoring systems, creating distributed interactive intelligent tutoring simulations.

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TELEPRESENCE AND INTERVENTION ROBOTICS

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ABSTRACT

In the field of Mobile Robotics applications dedicated to inspection or intervention in hostile, unreachable or unstructured environments, human operators are "processed" in the control loop developed for a Telepresence System. On the one hand dynamic situations suffer from a lack of automation degree by mobile robots but on the other hand a complete task robotisation can run counter to economic or human constraints. In mine clearance activity for instance, mobile robots and especially teleoperated semi-legged robots can be seen as a solution, not to replace the mine clearance specialists, but as a safe tool for human operators in some well-defined situations.

As human interaction with a machine is often oriented towards application, the teleoperation of a mobile robot under geometrical constraints is not easy to achieve if no training period occurred previously for the operator. A footbridge exists between training and relevant missions on navigation tasks: a real activity with a mobile robot can be prepared in a micro-world – a virtual world or an Augmented Reality world.

But the use of Telepresence systems, presented here as destined for an inescapable expansion because of cultural yearning with ancestral roots, is submitted to human factors. In this paper, after a discussion about the ubiquity myth in Telepresence, we present a Telelocomotion system with a Control-Command-Communication (C3) strategy adapted in a Service and Intervention context to semi-legged robots like our RAMSES (French acronym for Mobile Autonomous Robot with an Advanced Support System). The vision aspect is focused on and vision sickness issues generated by the motion of visual feedback are analysed. Some solutions to avoid or diminish troubles with either an appropriate camera or specific control laws are presented. Experiments are in progress to study the relevance in Telelocomotion of a Behavioural Transform by means of gestures produced by a dedicated optical fibre glove to operate a legged robot in comparison with the use of a joystick.

INTRODUCTION

In the field of Mobile Robotics applications dedicated to inspection or intervention in hostile, unreachable or unstructured environments, human operators are "processed" in the control loop developed for a Telepresence System. On the one hand, dynamic situations suffer from a lack of automation degree by mobile robots, but on the other hand, a complete task robotisation can run counter to economic or human constraints. In mine clearance activity for instance, mobile robots and especially teleoperated semi-legged robots can be seen as a solution, not to replace the mine clearance specialists but as a safe tool for human operators in some well-defined situations.

Different investigations are possible when dealing with legged robots and dedicated tasks. At the L.R.P. (Laboratoire de Robotique de Paris), we focus our attention on problems related to the stability of quadruped robots with a "force control and distribution" approach [Nak.89] [Kim.90]. Currently we study legged robots with respect to various situations (different topologies, rough terrain, partially unknown environments). Such an aim requires matching the task to be accomplished and the mechanical specifications of the robot. We have observed in many cases that hybrid structures (e.g., legs plus wheels) [Vil.93] [Fon.94a] are very well adapted to navigation tasks in some ways like stability (i.e., teleoperation is facilitated if the general instability of the robot is overcome).

As human interaction with a machine is often oriented towards application, the teleoperation of a mobile robot under geometrical constraints is not easy to achieve if no training period occurred previously for the operator. A footbridge exists between training and relevant missions on navigation tasks: a real activity with a mobile robot can be prepared in a micro-world – a virtual world or an Augmented Reality world.

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TELEPRESENCE

Introduction

In French language dictionaries the « Telepresence » neologism is not yet referenced. However, more and more researchers and manufacturers take an interest in Telepresence. This first section deals with ubiquity and myths becoming Virtual Reality in order to try to explain the inescapable expansion of Telepresence.

Ubiquity

« Ubiquity Society »

According to Jean Cazeneuve, a contemporary French sociologist, we are a « ubiquity society » [Caz.70] [Alb.95], resting on audio-visual media, extraordinarily rapid diffusion of hertzian waves adding an almost instant-dimension to its universal nature. Does that mean that people daily apprehend media with ubiquity characteristics and that it is possible to be present in several places at the same time?

In any case, this is the viewpoint of several contemporary researchers. Media like printed matter, painting reproductions, disks, and most of all *telematic networks, and information highways,* are said to allow ubiquity in works of art and information [Asc.97]. As early as 1928, Paul Valéry, in a visionary text [Val.28], was considering « a sort of ubiquity » for works of Art, imagining a future home-distribution with techniques from a so-called « Sensitive Reality » without anything less than what is called today « Virtual Reality ». Moreover, there ar many e who consider that going on the air, on television, speaking on the phone, are many ways to have a certain type of ubiquity [Alb.95] [Bal.95].

But is it right to talk about ubiquity in these cases?

« Corporal Ubiquity » and « Virtual Ubiquity »

Most adult human beings have an image of themselves, from their bodies [Sch.68] [Cor.72], that causes them to understand that the type of ubiquity we designate as « corporal » is unrealistic: except in some primitive tribes and among some heautoscopic trouble-related illnesses, the mirror image is just an image of the proprioceptive body. Our human condition and our world perception do not permit considering ubiquity in any other way than the « corporal ubiquity ». Now it is no more possible to be the same human being in several identical bodies, than to exist in several places at the same time, acting differently on the environment in different places (or in one place) like Marcel Aymé's heroine in its short story Les Sabines [Aym. 43].

Going on the air, on television, speaking on the phone, is the option to be « virtually ubiquitous ». Only a voice « image » is transmitted quasi-instantaneously, then is presented in several places, though the direct voice and the real body that produces this voice exists in only one place.

Mythology and Theology

The « immemorial ubiquity dream » [Bal.95] of man, namely « corporal ubiquity », appeared in mythology and theology: the Brahman [Ind.95] [Sid.95] and Greek pantheons [Pyt.95] had the fanciful gift well before the monotheist religions

initiated the ubiquity dogma [Bre.95] [Dum.95]. If the pluri-presence[2], and precisely « virtual ubiquity » can be considered for human beings thanks to brand new technologies like Virtual Reality, the pluri-existence is and will be reserved to gods: the Visnu avatars and the Trinity are a few examples. Jean-Paul Papin sums up the discussion as follows [Pap.97]:

« Ubiquity is to presence what Trinity is to existence »

Trinity deals with several beings being together, that « are » and « exist », though ubiquity deals with the same being, present in several places at the same time.

Telepresence and «Quasi Corporal Ubiquity»

Then, is it right to speak about ubiquity – meaning "corporal ubiquity" – in Telepresence?

« Quasi Corporal Ubiquity »

We have tried to demonstrate that « virtual ubiquity » is possible by means of a hardware and software interface. Then to be able to talk not only about Telepresence but also about « quasi corporal ubiquity » it is sufficient to have at one's disposal:

- A control-command-communication software and hardware architecture that allows one to have a distant image of oneself, which is mobile and controlled with a one-to-one relation,
- Sensorial feedback, sufficient to give the impression of immersion in a distant, real environment, because of the previous architecture,
- Physical action abilities in this environment.

It is only in the situation where the operator action has an effect in a world where he is supposed to be, that Telepresence can be talked about.

Robot Concept

The mobile robot is an operator image as the operator himself is in God's own image in Judaeo-Christian tradition. It has its own future in case of operator/teleoperator interface malfunction.

The robot concept dates back to ancestral desires. The Hephaistos god, in Greek mythology, built some obedient voice-operated « tripods » to help him with his forging work. It was only in the '20's that some « little artificial anthropomorphic beings perfectly obedient to their masters » were designed for the first time, designated by the term « robot », in a play called « R.U.R. » (Rossom's Universal Robot) [Tsc.20][Coi.82], by the Czech Karel Tschapek.

If the Oxford dictionary defines the robot as follows: « a mechanical apparatus resembling and doing the work of a human being », it is not well accepted even in the '80's because « no existing and useful robot is alike human » [Coi.82] at this time. Nowadays, the expansion of biped, quadruped or hybrid mobile robots validates the robot formal definition especially if it is brought together with the Sagittarius concept [Fon.95].

Sagittarius Concept

A mythical creature illustrates the « quasi corporal ubiquity »: the Sagittarius. It is particularly interesting to point out that a human operator can be directly superimposed on a robot. For that, we need to see the human locomotion and the gripping actions as the exact replica of what can be done by the front part of an antic creature: a Sagittarius (Figure 1).

[2] Presence in many places at the same time

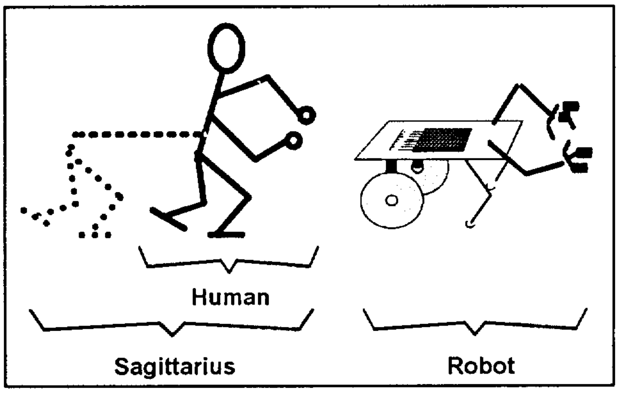

Figure 1. Morphologic Equivalence Between a Human, a Sagittarius and a Robot

It is also referred to as the mythical creature, half a man and half a horse, called a Centaur. The Sagittarius' humanoid upper human body is dedicated to gripping and sensitive functions, it holds a bow (a tool!). The locomotive lower body comes from a horse.

A one-to-one relation exists between the operator (the Sagittarius) and the teleoperator (the robot). The rear parts of the robot and the Sagittarius tend to improve the teleoperator stability and are totally controlled by the front part: the rear of the horse corresponds to the robot part that follows the "Leader". In our case, the wheels placed at the rear provide the global stability of the system without the contribution of the human "virtual" rear legs. The leaders are in the front and are directly operated by the operator's legs.

TELELOCOMOTION SYSTEM

Semi-Legged Robot

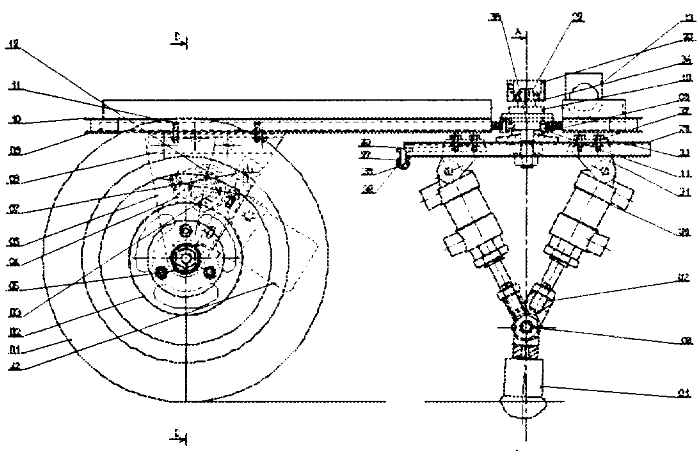

Figure 2. Layout of RAMSES IIb.

We developed a mini semi-legged mobile robot called RAMSES IIb based on RAMSES and RAMSES II presented in [Fon.94b][Cis.95]. This robot has front pneumatic legs and powered wheels at the rear for better support (wheels placed in Gordini way) (Figure 2).
It is able to walk (and roll) in an automatic or teleoperated mode to achieve what is called *Telelocomotion* [Khe.95]. This type of robot affords a quasi-unconditional stability and has been designed keeping in mind small obstacle avoidance under teleoperation routines.

It is necessary to teleoperate the robot with the most direct relation between the operator and the mobile robot in order to provide an ergonomic human-robot interface. For that, we need the one-to-one relation given by the Saggitarius concept (Figure 1).

In order to facilitate the development of a demonstrator, two operator fingers are equipped, instead of his legs: the movement is produced by an optical fibre-based dataglove called *LightGlove©* (Figure 3) that we especially developed for this application, which covers the hand of the operator. The robot legs copy the operator fingers [Fon.94a] [Fon.94b] [Khe.95] [Fon.95] [Cis.95].

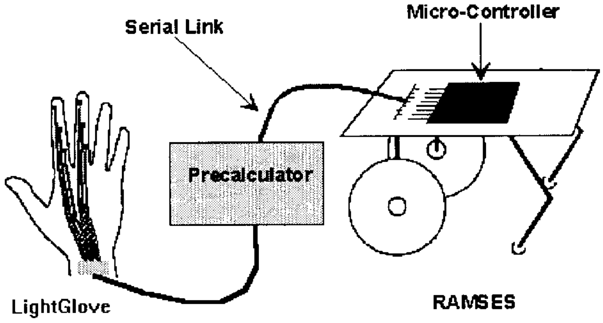

Figure 3. Legs Control with the Fingers.

Obviously, a very efficient way to teleoperate a system can be a Telepresence system which uses modern tools (e.g. Virtual Reality), and as far as possible direct relations between human abilities (physical and psychological) and the robot's characteristics.

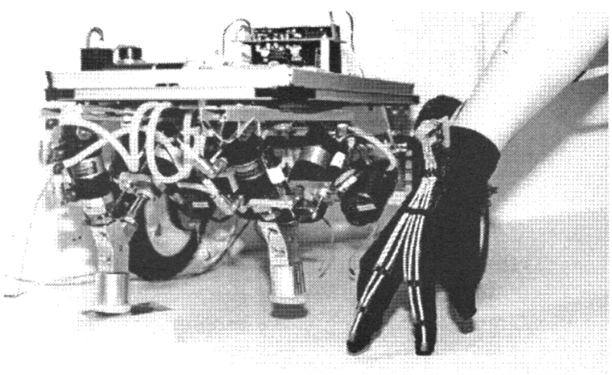

Figure 4. RAMSES IIb and the LightGlove©

TELELOCOMOTION DEVICES

During the teleoperation mode, the operator is fitted out with a two-finger LightGlove©. The robot speed is controlled directly by the finger flexion speed. For visual feedback, the operator is assisted by a method which keeps his hands free. The environment is re-created in conjunction with *virtual cameras* fixed to the robot or according to the choice of the operator.

The robot direction is determined according to the yaw of the arm's proximal part around a fixed (vertical) axis through the forearm. The command is eased by a special cradle, the main component of the telelocomotion device presented in [Fon.95]. However, it may appear that the ergonomic constraints taken into consideration for the development of this device would not be sufficient to assure a global physico-psychological comfort to the operator.

VISION SYSTEM FOR TELELOCOMOTION

D. Ernadotte and S. Neuman [Ern.94] asserts that, during Telepresence, « it is important to have a general view of a scene and more precise views for manipulations ». From the two types of tasks to execute (*navigation* and *mission*), we classified two sorts of video systems embedded in the telelocomotion system [Cis.96]:

- A long distance video system, allowing the operator to locate the robot in its environment,
- A precise video system, efficient at a short distance, for sharp missions (inspection, obstacle avoidance, fine object manipulation with a gripping device).

D. McGovern [Gov.93] gives experimental results about several types of video equipment on mobile wheeled robots with different architectures, on very unstructured grounds with obstacles: *positives* (bumps) or *negatives* (holes).

To determine the appropriate video system for each of the two types of tasks mentioned above, we studied [Gov.93] and synthesised the results of experiments about video systems on teleoperated all-terrain wheeled robots.

Navigation

In navigation, our concern is with robots that can be piloted:

- Out of visual reach,
- Or into the operator's visual field.

The out of visual reach Telelocomotion requires an embedded video system. It is called « inside-out » teleoperation [Gov.95] with an « eye of snail » vision [Pap.95].

But when the mobile robot is in the operator's visual field, the pilot sequences may be achieved:

- Either directly, with an "eye of God" view [Pap.95],
- Or in the same conditions as in out of visual reach, only with the "eye of snail" view,
- Or semi-directly by means of a video system located on another robot we called "relay robot". In the mine clearance activity, robots of different sizes and velocities step in: a main robot can be accompanied by little, simple and very quick robots it supervises, whereas the others examine closely the suspicious objects.

In the case of a unique semi-legged robot to teleoperate the solution we propose for navigation is an embedded video system. In order to allow the location of the robot in its environment, it is necessary to have a *periscope* type device with a 360° visual field.

However, additional direct or semi-direct information does not have to be excluded when available. The visual information fusion, performed by the operator, can avoid some incidents listed by [Gov.93]:

- Roll-overs in « inside-out teleoperation »,
- Frequent collisions with obstacles in "outside-in teleoperation".

During navigation, a black and white camera can be sufficient. However, it can be useful to discriminate surfaces merged in black and white (a road and its sides for instance), and therefore is preferred a colour camera.

It must be noted that with a quick robot, rounding bends is easier when a camera rotation allows anticipating the curve to follow [Per.94]. This anticipation is feasible with a camera directional control on:

- Either the glance direction [Per.94],
- Or the legs' direction.

Mission

In the case of a video system dedicated to missions, it is interesting that colour is preferred for better detection of objects and obstacles.

D. Ernadotte et al. [Ern.94] conclude from a series of experiments that automatic systems of convergence and autofocus must be added on stereoscopic visions. We think that these devices are appropriate, but we stress the fact that they must be disconnectable by the operator during the task.

VISION SICKNESS

A vision system, even well-adapted to the task to execute, can generate troubles if it is placed on a mobile platform.

From previous studies, and especially from [Oma.93], it appears that: « "Motion Sickness" is the general term describing a group of common nausea syndromes originally attributed to motion-induced cerebral ischemia, stimulation of abdominal organ afferent, or over-stimulation of the vestibular organs of the inner ear. Sea-, car- and air-sickness are the most commonly experienced examples. However, the discovery of other variants such as Cinerama-, flight simulator-, spectacle-, and space- sickness in which the physical motion of the head and body is normal or absent has led to a succession of "sensory conflict" theories which offer a more comprehensive etiologic perspective. Implicit in the conflict theory is the hypothesis that neural and/or humoral signals somehow traverse to other centres mediating sickness symptoms. »

We propose to reduce the general term *Motion Sickness* to *Vision Sickness* [Cis.96] when it deals with symptoms due to a sensory conflict between visual stimuli from a picture in motion (provided for instance by a real or virtual scene on a screen) and a normal (or absence of) kinaesthetic feeling. Vision Sickness may then accompany every system with real or virtual visual feedback.

In our telepresence system, visual feedback can provide vision sickness in three ways, corresponding to the three degrees of freedom (DOF) of a vision system placed on the platform of a semi-legged robot: pitch, roll and yaw.

Pitch Sickness

The most obvious sickness is associated with the pitch generated by the robot pneumatic leg height variations during a walking cycle [Khe.95]. At high velocity, the fuzzy and jerky visual feedback is as unusable as uncomfortable.

Roll Sickness

Though the roll is suppressed by the wheels at the rear on a flat terrain, it still exists on a very unstructured ground on which our robot is mainly dedicated to be teleoperated. This DOF may independently provide this type of discomfort.

Yaw Sickness

The last (but not the least) DOF sickness may be generated by a mismatch between the video system yaw and the robot direction changes or between the video system yaw and the kinaesthetic way it is operated: P. Peruch, at the end of his presentation of [Per.94], put forward an additional commentary about operators sickness provided when a 1-to-2 ratio exists between a head yaw controlling the direction of a virtual robot and the robot gaze direction, in order to give a better anticipation of a curve. This disorientation, obviously due to a sensory conflict, is our concern when using a periscope camera and must induce the camera command choice.

SOLUTIONS TO AVOID VISION SICKNESS

We propose different solutions (the list is non-exhaustive) to avoid each type of vision sickness in our telepresence systems. Our study takes a range of grounds and gaits into account: the best solution depends on the telelocomotion nature. Solutions are gathered according to the DOF on which they act.

Tilt Sickness Avoidance

The tilt ε due to the pitch phenomenon of the platform (the "back" of the robot) is represented in Figure 5. In order to suppress pitch sickness, it is possible to intervene at least at three stages:

- Obviously, to avoid the pitch of the robot when it walks it is possible to keep α and ε constant. This tilt can be minimised (at least completely compensated) as described in [Khe.95], by reducing the attainable domain of the legs' ends given an intermediary platform height, with controlled pneumatic jacks' lengths. Therefore, this solution is efficient in a flat terrain but has disadvantages on a very unstructured one: the leg height compensation unfortunately leaves the variations due to the terrain unchanged.

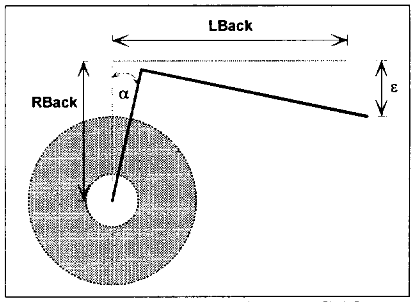

Figure 5. Pitch of RAMSES

- In a similar way a controlled camera platform can compensate the tilt with an identical ε, not restraining the leg attainable domain. This solution can directly use the results of [Ber.96]: it deals with an anthropoid stereoscopic foveated vision system with 4 DOF, 2 for its head motion and 2 for its eyes motion: « The Vestibulo-Ocular Reflex couples the movement of the eyes to the motion of the head, thereby allowing an organism to keep its gaze fixed in space. This is achieved by causing the motion of the eyes to be equal and opposite to the motion of the head. The VOR control system is typically modelled as a transformation from head velocity to eye velocity. » [Jor.90] cited in [Ber.96]. This solution however has the same disadvantages as the previous one.

- A more behavioural solution consists of applying the techniques described in [Ber.95], the additional tilts are due to the legs and to the terrain being taken into account. An optic flow technique using only a few points in the real or virtual image can be associated with a gyroscope placed on the robot platform to avoid lags.

- On either flat or unstructured terrain, the behavioural solution can be aided by an additional leg variation suppression (pitch suppression).

However, in the behavioural solution, it is necessary to determine the gaze control in both teleoperated and automatic modes where it appears that they are non-trivial problems. They are far beyond the scope of this paper but are the purpose of intensive research in our telepresence design frame. In teleoperated mode it implicitly deals with the interpretation of the operator *intention declaration*. In automatic mode, the gaze control can not be directly derived from previous studies where it is believed that « attention is captured by motion » [Ber.96]. From a camera point of view on a mobile robot, the entire environment is moving.
A relation must be found with the known concept of *visual search* [Wol.94] cited in [Ber.96].

Terrain Types ➡		Flat		Unstructured
Authorised Speeds ➡		**High**	**Low**	**Low**
Authorised Locomotion Mode ➡		Automatic	Teleoperated or Automatic	Teleoperated
Authorised Teleoperation Mode ➡		Navigation	Mission or Navigation	Mission
Periscopic vision system (farther vision)	Variations compensations required	Legs		Legs + Ground
	a) pitch suppression	sufficient		not sufficient
	b) camera platform compensation	better than pitch suppression		not sufficient
	c) horizon tracking	usable and efficient		usable and efficient
Stereoscopic vision system (nearer vision)	Variations compensations required	not relevant	Legs	Legs + Ground
	a) pitch suppression	not relevant	sufficient	
	b) camera platform compensation		better than pitch suppression	
	c) object tracking		usable and efficient	

Table 1. Efficiency of the different compensation methods to avoid tilt sickness according to the terrain nature

The behavioural solution seems to be the best to avoid tilt vision sickness. However, the best solution available depends on the nature of the telelocomotion. Table 1 synthesises our research according to the different terrain types and paces. The latter matches the several locomotion modes in teleoperation described in 0.

Roll Sickness Avoidance

To avoid roll of the visual feedback, it is possible to use the same techniques as those analysed for the tilt. However, it must be noted that if a correspondence may be made between the observations in [Gri.87] and vision sickness, it is more relevant in the case of roll than tilt. A. Griffin proposes a method to predict motion sickness in marine or other environments where vertical oscillation occurs at frequencies below 0.5 Hz. We intend to investigate a parallel configuration with horizontal picture oscillations during roll.

Yaw Sickness Avoidance

Taking into account the results of [Per.94] already discussed in section 0, it is important to precisely define the vision system yaw command:

- The periscopic camera must be independently operated in yaw from the robot direction in order to allow anticipation and localisation in the robot world. Depending on the application context, we propose the use of either a high-definition vision helmet or a head tracking system with screen display. However, we insist on the avoidance of ratios other than 1-to-1 between the head motion and the image display movement to suppress the operator disorientation and yaw sickness. Regardless, it must be added that during robot halts, a manual command must permit a horizontal investigation of the world on 360°.
- The stereoscopic video system must be operated by the same interface as the periscopic system, mostly during halts, without forgetting the disconnectable automatic facilities.

Generally, we must retain, too, the solution presented in [Oma.93] to avoid what we called vision sickness: a prediction to smooth the feedback image display derived from the Observer Theory and Kalman filters.

EXPERIMENTS

Experiments are in progress to study the relevance in Telelocomotion of a Behavioural Transform by means of gestures produced by a dedicated optical fibre glove to operate a legged robot in comparison with the use of a joystick. Variance analysis is used to interpret the results. A latin square in experiment protocols provide the order in which the groups of subjects are experiencing the different situations based on different vision feedbacks on a unstructured terrain. Time to perform the tasks and collisions with the real environment are measured.

As human interaction with a machine is often oriented towards application, the teleoperation of a mobile robot under geometrical constraints is not easy to achieve if no training period occurred previously for the operator. A footbridge exists between training and relevant missions or navigation tasks: a real activity with a mobile robot can be prepared in a micro-world – a virtual world or an Augmented Reality world. Pre-tests classify subjects in groups according to their skill level in driving a point on a screen with a joystick.

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This work would not have been possible without the daily support from Pr. Jean-Guy Fontaine from Laboratoire de Robotique de Paris (L.R.P.) and now from the Ecole Nationale Supérieure d'Ingénieurs de Bourges (E.N.S.I.B.), without the work done on RAMSES by our entire research team, and most of all without the precious advice from Dr. Jean-Paul Papin on human factors and experiment protocols.

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EXPLORATORY USE OF VR TECHNOLOGIES FOR TRAINING HELICOPTER DECK-LANDING SKILLS

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ABSTRACT

Canadian Forces (CF) pilots and landing safety officers require intensive training to develop the individual and team skills required for safe helicopter deck landings. These skills are currently acquired at sea, following individual training with independent simulators unequipped with visual displays.

DCIEM is exploring the feasibility of using commercial, off-the-shelf technologies as the essential components for simulators for training the pilot of the Sea King helicopter and the landing safety officer (LSO) of a Canadian Patrol Frigate (CPF). The objective of this project is to assess virtual reality and computer networking technologies that could be exploited in the development of a federation of interconnected, low-cost simulators. The human factors of visual and motion cueing, and coupling of the simulators, present the major technical challenges to the project's success.

This paper will describe the exploratory development models, some preliminary reactions, and the experimental plan proposed to assess the training effectiveness of the helicopter simulators.

BACKGROUND

In 1993, DCIEM completed the exploratory development of the Maritime Surface/Subsurface Virtual Reality Simulator (MARS VRS) that made use of virtual reality technologies for training ship handling skills. A low-resolution, biocular, head-mounted display was employed to provide a student officer-of-the-watch (OOW) with a view of his bridge and the surrounding environment, including other ships, so that he could acquire the skills needed to perform formation manoeuvres. Visual judgements of the ship's relative position, orientation and their rate of change guide the OOW's behaviour as do auditory communications among the bridge crew. Voice recognition was used to interface the OOW with a surrogate bridge team that responded to his spoken commands and automated voice production was used to provide orders to the student as a yeoman would normally read them aloud; different voices were used to provide the verbal information that other members of the bridge crew would normally speak aloud during the conduct of a manoeuvre. The behaviours of the other ships in the formation were guided by textbook solutions particular to the sequence of orders that formed the lesson plan.

The results of a transfer-of-training experiment, which compared the performance of students trained with the simulator for a week to the performance of students who followed the regular programme of instruction that made use of a gate vessel, indicated that the MARS VRS simulator better prepared students for formation manoeuvres when they had to perform them for the first time at sea with a mine sweeper. Simulator sickness questionnaires indicated incidence rates and severity reports similar to those of conventional aircraft simulators and tests of postural stability using a force plate found no evidence of ataxia associated with training.

On the basis of these positive outcomes, three MARS VRS simulators were later interconnected. Each was operated by a qualified officer, at widely separated locations. Although the simulators were physically apart by as many as 5000 kilometres, distributed interactive simulation permitted the officers to conduct formation manoeuvres within the virtual environment as proficiently as they would be expected to perform them at sea, where they are normally within 300 metres of each other.

HUMAN FACTORS ISSUES

The results of the transfer of training study indicate that positive transfer-of-training can be obtained with simulators using low-resolution, head-mounted displays for training visually based tasks that do not seem to demand high quality

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imaging; ships in formation are large, slow-moving and relatively close, although simultaneously beyond the range for human stereopsis. The results of the networking trial indicate that close coupling of the simulations is not a significant concern for formation manoeuvres since the ships move slowly and the tolerances for formation manoeuvres are large (within 10 metres) relative to the spatial congruency afforded by distributed interactive simulation technologies (i.e., less than one metre).

In comparison, the deck landing tasks present greater challenges to the successful exploitation of virtual reality and interactive networking for training. The pilot of the helicopter must make accurate judgements of surface orientation and distance well within the range of stereoscopic perception. In the North Atlantic, fog will often obscure the horizon and close proximity to the hangar face will limit the pilot's ability to make visual judgements of orientation or position independent of his immediate surroundings. The relative motions between ship and helicopter will therefore present an ambiguous visual environment to the pilot, who will not likely be able on the basis of visual cues alone to determine whether the ship, for example, rolled to the left with a wave or whether the helicopter rolled to the right with air turbulence. Without physical motion cues, the landing safety officer could similarly be confronted with an ambiguous situation when he must assist the pilot in achieving an accurate touchdown. Centimetres matter, and close-coupling of the LSO's and pilot's visual environments, in time and space, seems to be a clear necessity for simulator team training. The purpose of the current efforts are to determine whether virtual reality technologies can provide the visual and motion cuing needed to perform helicopter deck landing team training, and whether the High Level Architecture, is suitable for real-time, interactive networking in this scenario.

EXPLORATORY DEVELOPMENT MODELS

In order to assess the efficacy of the available technologies three exploratory development models are being constructed. Two will simulate the Sea King helicopter; each will be linked eventually to an LSO simulator and an existing MARS VRS. The two Sea King simulators differ dramatically in the cost and complexity of their components. The first, now ready for test flights, has been developed by the University of Toronto Institute for Aerospace Studies, employing state-of-the-art (SOA) components. The second, now being integrated by DCIEM, employs commercial off-the-shelf (COTS) components. A comparison of system components is shown in Figure 1. The LSO simulator, still under development, also employs the COTS technologies identified in Figure 1.

Figure 1 - Comparison of System Components

UTIAS	DCIEM
• FOHMD	• VR4 HMD
• CAE MaxView IG	• SGI Onyx IG
• 6dof, hydrostatic motion platform	• 6dof, COTS motion platform
• McFadden force loaders	• ROMAC force actuators, maybe
• GenHel aeromodel	• GenHel aeromodel
• DREA/Fredyne sea state modelling	• DREA/Fredyne sea state modelling

EXPERIMENTAL PLANS

The experimental plan requires two sets of comparisons, relying on three groups of subjects. The first set of comparisons is a reverse transfer-of-training assessment. Once test pilots complete acceptance of the SOA simulator, a group of

qualified Sea King pilots will be invited to fly the simulator. They will make many deck landings as students would practice them at sea. The experimental conditions will not simulate the recovery systems or provide guidance from others. The task will be performed at the limits of the operational envelop for free-deck landings (i.e., at the maximum values for the combination of wind and ship motion permissible without use of the tether). A second group of helicopter pilots without deck-landing experience will be invited to learn this task by performing it in the simulator. Later, the performances of the two groups will be compared. If the SOA simulator provides an appropriate environment in which the skilled behaviour of the Sea King pilots can be exercised then they should show little learning and do well. The other group of pilots should not do as well initially, and should improve with practice.

The second set of comparisons is an intersimulator transfer study. The behaviour of a third group of helicopter pilots without previous deck landing experience at sea will be compared to the first two after they have been given training on the COTS device. If the COTS device provides an appropriate environment for learning deck landing skills, then this group of pilots ought to demonstrate positive transfer of training to the SOA simulator if it is validated by the reverse transfer-of-training comparison.

The suitability of the High Level Architecture for team training will be investigated after the transfer studies are complete.

PRELIMINARY INDICATIONS

An early version of the exploratory development model of the LSO simulator was recently used as a virtual prototype to assist naval architects in their effort to redesign the workstation that now limits the LSO's ability to view the helicopter when it makes a starboard approach to the deck of a Canadian Patrol Frigate. A VR4 head-mounted, binocular display made by Virtual Research was used to display a virtual environment generated by an Silicon Graphics Infinite Reality Engine. The computer generated imagery consisted of the howdah, Sea King, hangar and deck of the CPF. The visual representation of the howdah was matched to different plywood mockups that constrained the movements of the observers realistically. LSOs viewed animations of the Sea King as it approached and landed upon the deck. They were very positive about the potential use of the visual imagery for the deck landing tasks. This is an encouraging result since LSOs are also deck qualified pilots.

SHARED VIRTUAL ENVIRONMENTS FOR COLLECTIVE TRAINING

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ABSTRACT

Historically NASA has trained teams of astronauts by bringing them to the Johnson Space Center in Houston to undergo generic training, followed by mission-specific training. This latter training begins after a crew has been selected for a mission (perhaps two years before the launch of that mission).

While some Space Shuttle flights have included an astronaut from a foreign country, the International Space Station will be consistently crewed by teams comprised of astronauts from two or more of the partner nations. The cost of training these international teams continues to grow in both monetary and personal terms. Thus, NASA has been seeking alternative training approaches for the International Space Station program.

Since 1994 we have been developing, testing, and refining shared virtual environments for astronaut team training, including the use of virtual environments for use while in or in transit to the task location. In parallel with this effort, we have also been preparing applications for training teams of military personnel engaged in peacekeeping missions. This paper will describe the applications developed to date, some of the technological challenges that have been overcome in their development, and the research performed to guide the development and to measure the efficacy of these shared environments as training tools.

INTRODUCTION

Many Space Shuttle flights include an astronaut from a foreign country. These astronauts usually carry out most of their training at the Johnson Space Center in Houston or in special facilities at other NASA centers. These astronauts often relocate their entire family to Houston. Thus, the support of international crews for the Space Shuttle has been at great cost to the nation from which the astronaut comes and has had a high personal cost for both the astronaut and his or her family. The International Space Station (ISS) program is a partnership between NASA, the European Space Agency, the Japanese equivalent (NASDA), the Canadian Space Agency, and the Russian Space Agency. The four-person crews that will staff the ISS will be derived from the partner nations and will also include guest astronauts from other countries. For years those responsible for training astronauts for the ISS have grappled with the issue of training these international crews. In order to reduce the costs of such training and to address the "political" issues of where training should occur, the NASA training community has sought means of training teams of astronauts, to some extent, while each astronaut remains in his or her home country.

Since 1994, we have been exploring the application of shared virtual environments for the training of international teams of astronauts. This task has encompassed a number of issues. Among these are necessary communications bandwidth, communications latencies, data transfer protocols, interaction metaphors, human figure representations, necessary fidelity (visual, audio, haptic), navigation methods, training transfer, and the psychology of team building.

In addition, the long duration and complexity of ISS missions precludes training personnel for all possible operations prior to the mission's commencement. Moreover, certain skills and knowledge acquired prior to a mission may degrade during the month's-long duration of typical ISS stays. Thus, VEs are being investigated to serve as delivery mechanisms for "just-in-time" training. In this case these systems could provide training just prior to the performance of a critical task for which no training was delivered prior to the flight or for which skills or knowledge may have degraded. It should also be possible to transmit new or updated databases to such space-based VEs to address specific unforeseen problems.

HUBBLE SPACE TELESCOPE MISSION

In December, 1993 the Space Shuttle captured the Hubble Space Telescope (HST), and astronauts carried out a complex set of procedures to correct its mirror's optical problems, replace and upgrade certain instruments, and carry

Paper presented at the RTO HFM Workshop on "The Capability of Virtual Reality to Meet Military Requirements", held in Orlando, USA, 5-9 December 1997, and published in RTO MP-54.

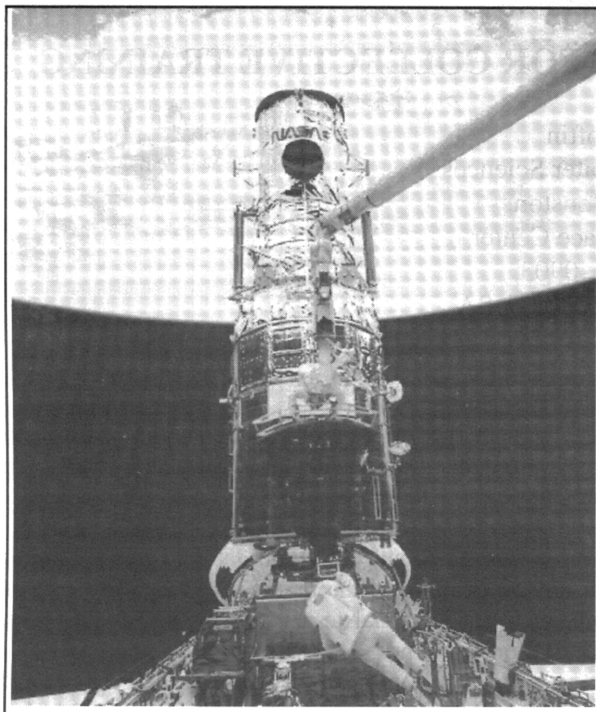


Figure 1. A team of astronauts prepares to maintain the Hubble Space Telescope during the December, 1993 mission

out planned maintenance (see Figure 1). This mission, by most measures, was the most challenging mission ever performed in the history of the United States' manned space program. Preparation for the mission was the most careful and detailed and brought unique resources to bear for the training of both astronauts and the ground-based flight team. In order to achieve the maximum state of readiness, virtual environments were used, for the first time, in the training of the flight team [Loftin, 1995]. This use of virtual environments for training joins a small set of applications that demonstrate the efficacy of this technology for training. Shortly after the conclusion of this mission, interest in using shared virtual environments to train international teams of astronauts emerged as a high priority within NASA's training community. NASA, the University of Houston, and the Fraunhofer Institute for Computer Graphics joined together to pursue an initial effort to determine the feasibility of a shared virtual environment for team training. The context for the feasibility study took the form of a simple extravehicular (EVA) simulation that engaged two astronauts, one located at JSC and the other in Darmstadt, Germany to reenact a portion of the 1993 HST mission. In this simulation, the two astronauts changed out the Solar Array Drive Electronics (SADE) in the HST.

Months of preparation culminated in a demonstration on September 20, 1995, as Astronaut Bernard Harris (physically located in Houston at the Johnson Space Center) entered a virtual environment with Astronaut Ulf Merbold (physically located at the Fraunhofer Institute for Computer Graphics in Darmstadt, Germany). Their shared environment consisted of models of the Space Shuttle payload bay and the Hubble Space Telescope. The two astronauts spent over thirty minutes performing the major activities associated with the changeout of SADE. Their work included the real-time hand-off of the replacement SADE in exchange for the original SADE. At the conclusion of the task the two astronauts shook hands and waved good-bye [Loftin, 1997]. Interviews with the astronauts after this experiment revealed their support of and interest in this mode of training. They confirmed its utility for mission planning and the familiarization phase of training and acknowledged its value in reducing travel and personal segregation from their families and home environments. The results of this singular experiment have led to sustained funding from NASA to continue developing the technologies needed for this type of training and to design and conduct experiments to identify human-human and human-machine issues that require solution if this approach to training is to become part of the baseline training for the International Space Station.

INTERNATIONAL SPACE STATION

Based on the success of the Houston-Germany experiment described in the previous section, we have been developing a testbed around the International Space Station. The training focus of this testbed is the conduct of scientific experiments and the execution of repair and maintenance operations within the ISS. Models of the interiors of selected ISS modules have been created (see Figure 2) and populated with both highly detailed, interactive models (polygonal) of the elements for which training has been developed along with detailed but non-interactive models (texture mapped) of the remaining interior elements. The racks of equipment for which training is delivered in this virtual environment comprise the Biotechnology Facility (BTF). Prototypes of these racks are currently on-board the Russian Mir Space Station, affording opportunities to investigate training transfer for currently-performed tasks (see Figure 3).

A major distinction between this experimental testbed and the environment used in the Houston-Germany experiment described earlier is the transfer of the training context from extravehicular activities (EVA) to intravehicular activities (IVA). Whereas in the EVA environment astronauts were represented as "suited" individuals, employing rather simple graphics to represent their bodies, in the IVA environment, high fidelity human models were developed to serve as avatars for the actual participants in virtual environment training. This approach sets a much higher standard for the fidelity with which the humans are represented and challenges the developers to find a reasonable compromise between fidelity and graphics display performance (see Figure 4). Training participants are instrumented with sensors

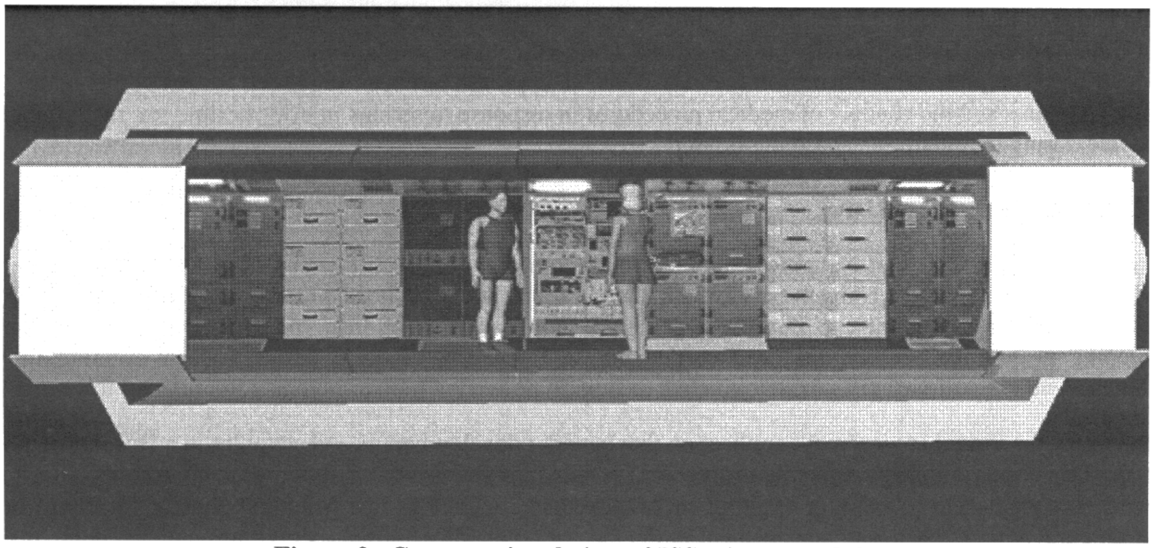


Figure 2. Cross-sectional view of ISS science module

that enable real-time tracking of critical portions of their bodies (typically the head, torso, and wrists). Using fast inverse kinematics [Tolani, 1996], we have implemented avatar motion for the arms that reasonably represents the actual motion of the human arm during the operations carried out by the tracked real arm. Work is underway to further refine these inverse kinematics and achieve even faster performance and more natural positioning of the entire arm [Yang, 1997]. This work seeks to combine the best features of the analytic approach described by Tolani and Badler [Tolani, 1996] with experimental results from neurophysiological studies [Lacquaniti, 1982; Soechting, 1989a; Soechting, 1989b]. Leg motion is not implemented in the current environment since it does not play a major role (at least in the sense of walking on the Earth's surface) for location in microgravity. Eventually, we will have to tackle this problem since leg position is important in some tasks where the human must exert substantial forces or torques on objects.

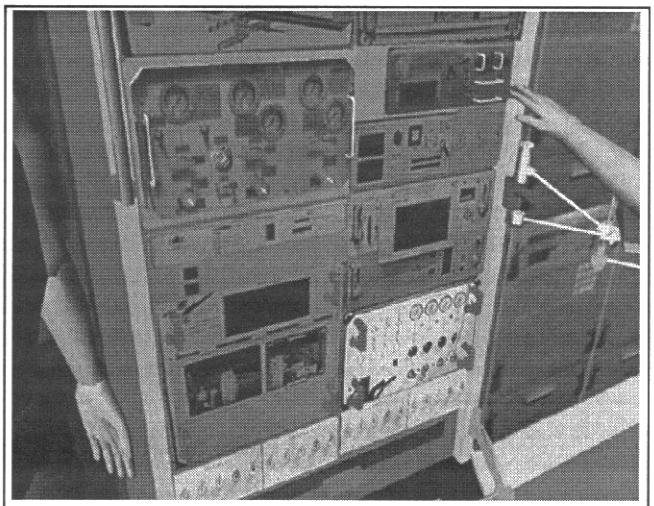


Figure 3. Model of the Biotechnology Facility in the ISS and on the Russian Mir Space Station

The current testbed has been implemented at three sites to support experiments in training two astronauts while other personnel (trainers or managers) are able to view the actions of the trainees via a "stealth" mode. That is, the stealth view is a stereo camera view that can be positioned anywhere in the virtual environment but has no manifestation in that environment that can be perceived by the trainees. Final experimental procedures are now being developed in preparation for controlled experiments using this testbed. The goal of these experiments will be a training transfer study to the "real" hardware (either in the Russian Mir Space Station or on the ground once the equipment is returned to Houston).

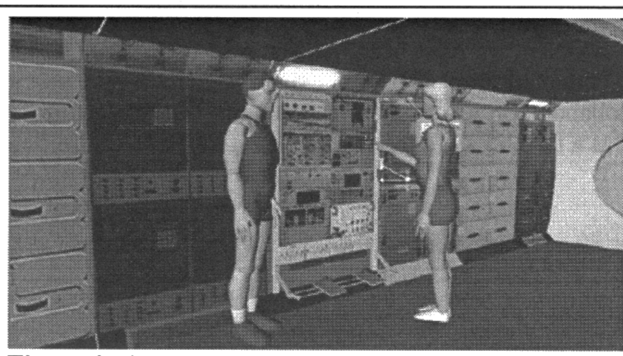


Figure 4. Avatars are used to represent astronauts in the ISS virtual environment

It should be noted that a major current thrust is directed at enabling the use of virtual environments in space to support "just-in-time" training. Such training, in low Earth orbit, might include environments shared by astronauts in the ISS and ground-based engineers and other professionals. Such an approach has been suggested for both emergency repair of complex systems and the conduct of medical procedures in response to serious injuries or illnesses that might be encountered during long-duration space missions.

PEACEKEEPING OPERATIONS

With support from the Office of Naval Research, a group (comprised of the University of Houston, the University of Pennsylvania, George Mason University, LinCom Corporation, and Lockheed-Martin) has been conducting basic research and applying its results to develop a prototype application to address training of military personnel in Peacekeeping Operations. Work has been carried out in two areas of basic research: team training in virtual environments and the utility of virtual environments to support nonverbal human-human communication.

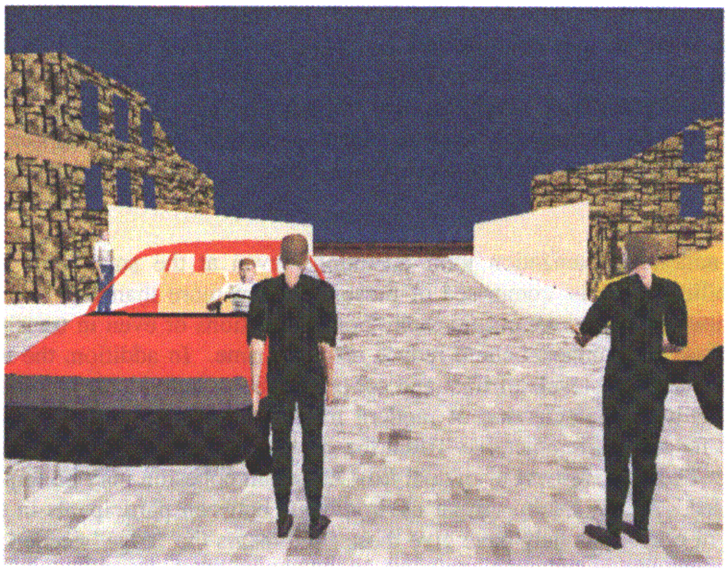
The context for the virtual environment application that is under development is a checkpoint in a Bosnian setting (see Figure 5). This scenario offers a versatile testbed for investigating the use of shared virtual environments for training small units (fire teams and squads) for carrying out peacekeeping operations in a potentially hostile location where the focus is on employing the Rules of Engagement in the face of potentially unfriendly civilians and an enemy operating in a covert manner.

Figure 5 – A U.S. soldier manning a Bosnian

This application is being used to investigate the degree of training transfer to similar, real-world settings (see Figure 6). In particular, we seek to challenge the trainees with distracters and to enable them to experience the consequences of failure to employ correct procedures and follow the Rules of Engagement. A typical training scenario might employ a distracter (an individual running across the soldier's field of view) aimed at drawing the attention of the covering soldier away from his teammate while that partner is engaged in checking the identification of the driver of a car stopped at a checkpoint. If the trainee's attention is drawn from "covering" his teammate, the consequence could be the driver taking a weapon from concealment and shooting the soldier who is attempting to check his identification. Thus, the results of distraction from one's assigned mission, can be forcefully brought home to the trainee.

In tandem with this application development we have been conducting a series of experiments in both team training transfer [Bliss, 1997] and nonverbal communication. The first experiments have focused on team navigation skills. A larger study is now underway, in collaboration with the Army Research Institute (Orlando Field Unit), to determine how well navigation skills acquired as a team in a virtual environment transfer to the setting represented by the virtual environment.

Figure 6. Scene from Peacekeeping Operations Environment



The second set of studies has not yet been subjected to peer review, but results of two separate experiments have been analyzed. These results demonstrate that subjects in typical virtual environments can reliably recognize stereotyped and some subtle human facial expressions. The reliability of recognition is comparable to that achieved by the subjects viewing photographs depicting the same expressions. Experiments are now being designed to investigate the degree to which the application that we have developed can provide training that is transferable to real-world analogues.

IN SITU TRAINING

NASA astronauts have consistently noted the need for training during spaceflight, even relatively short-duration Space Shuttle missions. Apparently they believe that some skills, such as landing the Space Shuttle, deteriorate during a two-to-three-week-long mission. In response, NASA has developed a PC-based system, delivered via a laptop computer, for landing refresher training. As mission lengths grow (e.g., International Space Station stays and future Lunar/Mars missions) from weeks to months and years, NASA must systematically address *in situ* training for crews. Clearly, much of this training can be provided via standard computer-based techniques. However, there are a significant number of tasks that demand interactive, three-dimensional representations in order to achieve the needed degree of realism (both visually and through body orientation and manipulation by hand). For example, astronauts currently plan their body placements for many tasks using virtual environments. Thus, research and development is underway to address the delivery of some training in space using virtual environment technology. The first virtual environment system will be flown aboard the Space Shuttle in mid-1998 as a part of Neurolab (STS-90). Although this system is intended for use in a human perception experiment, its development and flight clears the way for future space-based experiments that utilize virtual environments for training. It is anticipated that such an experiment will be conducted during a mission in late 1999 or early 2000. The success of this type of experiment will likely lead to the incorporation of a virtual environment within the International Space Station.

In addition to applications during long-duration Space Shuttle missions and aboard the International Space Station (both of which occupy low earth orbits), it is probable that virtual environments will be required for any human mission to the lunar surface or to Mars. In the latter case, transit times will exceed one year with total mission time occupying three or more years. Moreover, communication lags can reach thirty minutes and there can be significant periods (months in length) with no communication at all due to particular Earth-Sun-Mars alignments.

IMPLICATIONS FOR NATO

Other papers in this workshop have addressed the use of virtual environments for a variety of military training applications. The specific projects described in this paper, while not designed for typical warfighting training, do provide a basis for developing and/or improving virtual environment training for a variety of modern military

missions. In particular, the application of virtual environments for peacekeeping mission training should be of interest to NATO, given its current role in Bosnia.

The use of virtual environments (both individual and shared) for small unit mission planning and training offers a number of benefits. For example, unit commanders can plan and review tactics with appropriate superiors and subordinates. Whole units (or parts thereof) can rehearse entire missions or critical mission elements to resolve such issues as timing and personnel placement. Perhaps most importantly many options for attaining a specific mission objective can be quickly explored during the mission planning phase. Such an approach will likely result in a significant increase in the probability of mission success and a concomitant reduction in the likelihood of casualties (both military and civilian).

Since NATO is a multi-national organization joint operations, even at the small unit level, are likely. Shared environments offer the ability for units, comprised of personnel from more than one service and/or more than one nation, to rehearse a mission while they are still in their "home" locations or even in transit to the site of operations. Such an application of virtual environments could reduce response time. In addition, the time spent in these shared environments could lead to increased levels of trust and cohesion among individuals who have never met prior to the conduct of a mission. Finally, a characteristic of modern military operations is the fluidity of team composition. Teams may be constituted for a specific objective within the context of a larger mission. Such teams may only exist for hours or days, at most. The achievement of mutual trust and team cohesion may be impossible if traditional team training approaches are used. Again, shared virtual environments between participants in their "home" locations or while in transit to the site of operations may have give these fluid teams the "edge" needed to succeed in the modern battlespace.

ACKNOWLEDGMENTS

The author gratefully acknowledges the model development work carried out by Hector Garcia (ISS models) and Jan Lockett (human avatar models) as well as the compilation and analysis of training requirements and operational procedures conducted by Tim Saito. Lac Nguyen and Hector Garcia have been invaluable in implementing the virtual environment. Communications protocols used, in part, for this work were developed at Hughes Research Laboratories, principally by Peter Tinker and Kevin Martin. Support for this research has been provided by NASA/Johnson Space Center (through grants to the University of Houston and contracts with LinCom Corporation), the State of Texas, and the Office of Naval Research.

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FRENCH MILITARY APPLICATIONS OF VIRTUAL REALITY

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INTRODUCTION

France is now applying virtual reality techniques to military purposes. In parallel, France is conducting studies related to the psychological effects of immersion.

Our approach is based on the creation of synthetic environments in which men are more or less immersed. Besides we have been searching for the means that will give the best price/quality ratio. This resulted in creating environments which are both simplified and improved with respect to the actual environment. This document describes some current applications.

The 5 H's

First, it is necessary to define the range in which the virtual reality techniques will be applied. In our opinion, these techniques can be applied to five fields, i.e. the 5 Hs:

1. Help for design,
2. Help for test,
3. Help for training,
4. Help for mission preparation,
5. Help during operations.

1. This application is currently being undertaken at the Etablissement Technique d'Angers (ETAS). The purpose is to be able to simulate vehicle compartments and to analyse them in dynamic conditions.
2. It will be possible to use the above application to perform tests on currently developed equipment. This corresponds to the second type of application.
3. The third application is for personnel training and instruction.
4. The fourth application is related to the preparation of missions. Works are in progress to help special units to prepare interventions. The purpose is to replace the old sandboxes or even the real-size site reconstruction techniques with synthetic environments where soldiers can repeat the various actions to be carried out.
5. The fifth application for which we will give an example, is related to the use of these synthetic environments as an assistance during actual missions.

To illustrate training assistance, we will give three examples corresponding to different degrees of immersion. The first one is for parachuting, the second one for resuscitation gestures, and the third one is a film related to Leclerc tanks crew training.
Finally, an example will illustrate the use of these techniques as an assistance during a real mission.

Parachuting

The developed simulator is very similar to the one developed by Systems technology, Inc. The data processing means involved in its creation are not expensive. The synthetic environment is a simplified representation of the training environment that includes part of the Etablissement Technique d'Angers (ETAS). The parachute drift laws have been established from data recorded in flight by test parachutists of the Airborne Centre of Toulouse (CAP).

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A special effort has been made to simplify at the maximum the simulation supervision operations. The jump can be recorded and then shown to the trainee. It is also possible to modify meteorological parameters.

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The trainee can see both the parachute and his/her feet. In this application, the parachutist and his/her harness are immersed. The only "non-realistic" interface is the virtual reality helmet. The control actions are performed by acting on the real controls of the parachute.
This type of simulator, with its simple architecture and the reduced number of interfaces, has been received positively by professionals.

Front-Line Medical Care

The basic characteristic of France is advanced front-line medical care with the practice of medical and surgical operations on the actual combat spot.

The current type of military intervention is characterized by the engagement of a low-strength unit for which medical support is provided by a unit doctor who has a front-line armoured ambulance which can be used to evacuate wounded personnel. Very often, this involves emergency resuscitation which requires the practice of elementary resuscitation gestures. These gestures are characterized by the fact that they must be done blind, whether inserting a perfusion in the jugular vein, anaesthetizing the brachial plexus or placing a cannula in the trachea. Sometimes these operations have to be done inside the vehicle, in combat gear, with a heavy helmet and a bullet-proof vest; therefore, it takes place in a narrow, cramped space which is often hot and noisy and sometimes the individual is restricted in movement. The posture is often uncomfortable with the presence of combat stressors, in particular enemy fire. In addition, these operations are carried out by general practitioners.

In this context, Chief Medical Officer TRIFOT, director of CITERA in Lyons, had the idea of launching a training project using virtual reality techniques for the teaching of elementary resuscitation gestures. This project is partly financed by "Mission Innovation" at the DGA and involves different partners which, in addition to CITERA, include the Human Factors division of Etablissement Technique d'Angers (ETAS), the University of Angers, the Laboratoire Robotique de Paris and a firm of architects (Pierre Granjean).
At present, the tool is used as follows. The students learn to perform gestures by initially regarding the in-depth anatomy of the neck and the route followed by the needle in it. The pertinent elements of this anatomy are reinforced by colours. Subsequently, the student repeats these gestures while only seeing the skin but having an enhanced return of the manual sensation. Finally, he performs the activity with the same work field as in reality, i.e. with little manual sensation and a view of just the surface of the region. In terms of verification when the act is performed, the student can see the result by displaying the position of the needle in depth.

The last stage of training consists in doing this task in the GEPAT (Générateur d'Environnement Physique Aggressif pour le Travail). In addition to confinement, this generator, developed under the responsibility of Laurent Todeschini, ETAS, produces noise, heat, movement and hypoxy. The task is performed wearing combat gear, a bullet-proof vest and a heavy helmet.

To conclude, such a product should enable doctors to be trained how to operate in any critical situation through learning not only the technique but also the ability to face up to it.

The studies already carried out in the framework of this project lead us to draw a parallel between this front-line medical facility and manual mine-clearing actions: this resulted in the study of a device for exploration of heterogeneous layers, in both the mine-clearing and the medical fields.

Leclerc Tank Crew Training

The film shows a specific application where the immersion is obtained via a tank simulator that allows interactive training of the three crew members. This device is now operational and used to train all the Leclerc tank crews.

Assistance during Missions : Definition of a Virtual Area for Action (DEVA - Définition d'un Espace Virtuel pour l'Action)

The last presentation of this summary deals with the use of synthetic environments as an assistance to drive vehicles. The developed device includes an ETAS geographical database used to supply the drivers with a full-size reproduction of the field with a precision of +/- 2 cm for roads and 1 to 10 m for the rest of the area. In addition to this geographical

data, it is possible to integrate information such as road signs or identification of dangerous areas. As the driven vehicle is equipped with video cameras, it is possible to supply the pilot with a navigation aid by superimposing on the real images the synthetic information generated by the application.

The second driving mode is the "blind" mode (i.e., without seeing the outside of the vehicle and helped only by the synthetic geography). Note that the position of the vehicle is given with a precision lower than 7 cm by a GPS coupled with an on-board system. The tests performed in these conditions show that the pilots could drive their vehicles in "blind" conditions at a speed of approximately 45 km/h.

In addition to the above driving modes ensured by this device is the "God's eye view" mode: it can be compared with the way a child drives a remotely-controlled car. The future trajectories of the vehicle can be anticipated since this mode offers a long-distance vision. We can easily imagine its tactical applications. It is also possible to superimpose on this synthetic image the image of the actual landscape, for example from an infra-red camera showing obstacles. This allows driving by night without lights and in foggy conditions.
This application offers a high potential and in the future, instead of these screens, it should be possible to make a projection of the synthetic environments directly on the windscreen.

FORMATIVE EVALUATIONS OF THE VESUB TECHNOLOGY DEMONSTRATION SYSTEM

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BACKGROUND

Decreasing military budgets, reduced training infrastructure, and increasing complexity of weapon systems and missions mandate the exploitation of innovative advanced training technologies. In recent years, training developers have recognized the potential of virtual reality (VR), often called virtual environments (VE), as a flexible and effective training medium. A prime candidate area for examining the effectiveness and usability of VR systems is the training of the submarine surfaced ship handling task. Although land-based simulator facilities currently exist for training Submarine Piloting and Navigation teams, these systems do not provide detailed harbor and channel ship handling training for the Officer of the Deck (OOD). OOD training is primarily obtained from on-the-job experience, which is adversely impacted by the operational constraints of the Submarine Force, and the limited surfaced steaming time of submarines. Training that will expose junior officers to a variety of geographical and environmental conditions is very limited since most Commanding Officers place their most experienced OODs on watch during these challenging evolutions. Therefore, an alternative, high-fidelity, simulation-based training capability is needed. A VR-based simulation may provide this necessary capability if it is both effective and user-friendly.

OBJECTIVE OF VESUB

The goal of the Virtual Environment for Submarine OOD Ship Handling (VESUB) project is threefold: (1) to develop, demonstrate, and evaluate the training potential of a stand-alone virtual reality-based system for OOD training; (2) to integrate this system with existing Submarine Piloting and Navigation (SPAN) training simulators; and (3) to determine the viability of VR technology as a training tool.

DESCRIPTION OF VESUB

The VESUB technology demonstration system uses a high-resolution head mounted display (HMD) to provide the trainee with a simulated 360 degree representation of the visual environment containing many of the required cues associated with harbor and channel navigation as well as accurate cultural features and varying environmental conditions. Voice recognition and synthesis are used to provide communications training. Visual scene rendering, computation of harbor currents, wind effects, hydrodynamics of own ship and traffic ships require state-of-the-art hardware and software, including:

- Silicon Graphics Onyx Image Generation Computer (Infinite Reality configuration)
- n-Vision Datavisor HiRes HMD (1280 x 1024 pixels resolution)
- Polhemus 3 space Fastrack Head Tracker (Magnetic)
- ModelGen2 from Multigen, Inc. (creation of models and terrain)
- Vega Marine from Paradigm Simulation, Inc. (marine visual effects)
- HARK, Speaker-Independent Voice Recognition software

Additional details on VESUB hardware and software may be found in Hays, Seamon, and Bradley (1997).

VESUB DEVELOPMENT PHASES

The VESUB project was organized in three phases: 1) requirements determination; 2) formative evaluations; and 3) training effectiveness evaluations.

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Requirements Determination Phase

The requirements determination phase was the first year of the project. During this phase, a simplified feasibility demonstration system, developed under the NAWCTSD exploratory research Virtual Environment Training Technology project, was used to elicit VESUB system requirements from Navy subject matter experts (SMEs). The initial functional requirements were documented in a NAWCTSD special report (Tenney, Briscoe, Pew, Bradley, Seamon, & Hays, 1996) and used to direct the contractor during the development of the VESUB technology demonstration system.

Additional VESUB functional requirements and training objectives were developed around the organizing concept "Seaman's Eye," defined by the VESUB research team as follows:

> *Seaman's Eye: The total situation awareness of the ship handling environment and the ability to safely maneuver the vessel in all conditions.*

The perceptual and cognitive components of "Seaman's Eye" were identified and used to help determine hardware, software, and instructional requirements. Details on how the perceptual components were used to help select VESUB hardware may be found in Hays, Castillo, Bradley, and Seaman (1997).

Formative Evaluation Phase

Formative evaluations serve as initial tests of the configuration and instructional methods included in the training system. These evaluations help the training developer to avoid or correct costly mistakes before they are finalized in the configuration of the training system. The software development and hardware integration for VESUB was accomplished under contract by Nichols/Advanced Marine. The contractor developed the VESUB system at their offices near Washington, DC. The VESUB formative evaluations were conducted on a duplicate VESUB system in the laboratory at NAWCTSD during the second and third years of the project. Each time the development contractor produced an improved iteration of the software, it was installed in the VESUB laboratory and evaluated against the functional requirements. Over ten iterations of the system have been produced and evaluated.

Data for the formative evaluations were collected from a wide range of SMEs. These included: full time retired Navy submariners; active duty Navy submarine SMEs from the fleet and training facilities; and Navy reservists. Recommendation for system improvements were provided to the software developer for improvement of the next system iteration. A brief summary of the results of the formative evaluations are presented below.

Training Effectiveness Evaluations

The training effectiveness evaluation (TEE) phase will include TEEs of the VESUB technology demonstration system. The first TEE will be conducted at the Submarine Training Facility in Norfolk, Virginia during January 1998 and the second will be conducted at the Naval Submarine School in Groton, Connecticut during March 1998. The TEEs will use actual Navy trainees with various levels of experience (novice to expert) to determine the effectiveness of the VESUB system and also to help determine how the technology can be integrated into Navy training. During the Norfolk TEE, VESUB will be connected to the SPAN trainer to determine if the modern VESUB hardware and software can communicate with the older SPAN system. If feasible, the future operational VESUB systems will be interfaced to SPAN trainers to provide interactive OOD training with other members of the Navigation Team. The results of the TEEs and other lessons learned during the VESUB project will be documented for use in the acquisition of the operational VESUB systems.

Acquisition of Operational VESUB Systems

Current plans call for the acquisition of operational VESUB systems, beginning in 1999. The systems will be installed at the Navy's five major submarine training facilities. The VESUB technology demonstrations system will serve as a functional baseline, which will have to be matched or improved. The operational systems will include the functionality of the demonstration system and improve on this functionality, based on the results of the TEEs.

RESULTS OF THE FORMATIVE EVALUATIONS

VESUB formative evaluations focused on both the functionality of the trainee interface (e.g., the fidelity of objects in the visual scene or the responsiveness of the voice recognition system), and the usability of the Instructor/Operator Station (IOS). The results of the IOS usability analysis are presented in Hays, Seamon, and Bradley (1997). This report documents twenty-two areas where the design of the operational VESUB system IOS can be improved.
Hundreds of SME recommendations for improvement of the trainee interface were collected during the formative evaluations. These recommendations ranged from very general (e.g., improvements in the representation of equipment on the submarine bridge) to very specific (e.g., the logic supporting the "angle on the bow" display on the IOS). The recommendations were provided to the system developer and prioritized for inclusion in subsequent software iterations. Only a limited number of the recommendations could be included in the demonstration system due to budget, schedule, and technology constraints. For example, in March and April of 1997, seventy-three major system requirements were reduced to twelve. Two examples of requirements that were not implemented are: time varying fog (e.g., fog bank "rolling" in rather than instant reduction of visibility) and secondary propulsion motors (used when the rudder or main engine fails and for docking maneuvers). Two examples of requirements that were included in the system are: environment sounds (e.g., ship whistles, bells on buoys, wind, and rain); and latitude/longitude organization of the databases (rather than an x-y coordinate system as in previous ship handling trainers). An example of a partially developed function, which will require improvement in the operational system, is collision detection. Finally, several unanticipated requirements were recognized only after initial versions of the software were evaluated. An example of these unanticipated requirements is large area database management (required because of the need to display both close and distant objects in the visual field). Details on the trade-offs made during system development will be documented in a final "lessons learned" report.

CONCLUSIONS

The development of a complex training system, like VESUB, requires the dedicated efforts of a team of experts including: computer scientists, visual engineers, task SMEs, and instructional psychologists. It is essential that a substantial period of formative evaluations be included in the development of any such training system. It is not possible to anticipate even a fraction of the problems that will be encountered during system development. Formative evaluations provide the opportunity to correct problems before they are fully implemented in the system and become too costly to correct. As training systems, VE-based or otherwise, become more advanced, they also become more complex. This complexity brings unanticipated difficulties, which will require innovative and timely solutions. Formative evaluations provide the opportunity for system developers to apply these solutions at a stage where they can have a positive benefit to training system effectiveness.

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HMD BASED VIRTUAL ENVIRONMENTS FOR MILITARY TRAINING - TWO CASES

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ABSTRACT

This paper reports on two cases in which Head Mounted Display (HMD) based Virtual Environments (VE) are applied to military training. The first case deals with Forward Air Controller training, while the second case is aimed at Stinger training. Both applications are subjects of study within the VE research program of the TNO Physics and Electronics Laboratory and the TNO Human Factors Research Institute.

For the Forward Air Controller (FAC) training application a feasibility study was recently performed. Based upon a task and training analysis, a prototype FAC training simulator was developed and evaluated. Evaluation results have encouraged both the Dutch armed forces and other NATO countries (United Kingdom, Belgium) to seriously consider the HMD based FAC simulator as a useful and effective training tool. The paper describes the simulator prototype and evaluation results, including the human factors issues that were addressed in this study.

The Stinger training application is still in an early stage of development. Instigated by a demand of the Royal Netherlands Air Force, the research is focused on finding a suitable concept for a mobile training device. The paper describes a planned project (to start in 1998) that includes the development of an experimental system in order to evaluate several design alternatives. The evaluation has as a goal to determine how human performance is affected by the type of display system that is used, the overall system latency and the tracking accuracy.

INTRODUCTION

Beginning with the emergence of the technology, the TNO Physics and Electronics Laboratory has been researching the application of advanced Virtual Environment (VE) technology to military training and command & control problems [1]. One of the focal points in this research program is the use of Head Mounted Display (HMD) technology to provide a visual environment that fully surrounds the user, the main advantage of HMDs being their much smaller size then conventional projection display devices.

The use of HMD technology in virtual environments for training simulation has always been recognised to be of great potential. However, to date TNO has no knowledge of operational military training devices based upon this technology. The application of VE technology to the training of Forward Air Controllers and to the training of Stinger teams are likely to be among first cases that will change this.

In the remainder of this paper we provide a description of two research projects that are carried out on the application of HMD based virtual environment systems to the Forward Air Controller training problem and the training of Stinger teams.

Forward Air Controller Training Simulator

Initiated by a demand for more effective training tools at the Netherlands Integrated Air Ground Operations School (NIAGOS), the use of VE technology for training Forward Air Controllers was made the subject of a feasibility study. In a co-operative effort between the Royal Netherlands Army, the TNO Physics and Electronics Laboratory and the TNO Human Factors research institute, a study was carried out to determine whether an HMD based training simulator would be a valid and feasible solution to improve training effectiveness.

The Forward Air Controller (FAC) plays an important role in Close Air Support (CAS) operations. CAS operations are performed when air support is requested to attack enemy units that are in close proximity to friendly units. The task for the FAC is to guide the CAS pilots in the final stage of their mission such that they engage the correct enemy targets, without endangering friendly forces.

CAS pilots are briefed in advance on their mission objective and all relevant mission data. The brief includes information on the target position and describes the position of nearby friendly units, and possible threats the pilot may

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encounter. Based upon the specified target position, the pilot programs his navigation system that essentially guides him *roughly* to the target, taking into consideration the fact that there will be a certain error in the specified target position, that the navigation system has a limited accuracy, and that the target may be moving.

At this point the FAC comes into the picture. Based upon briefing data, the pilot will be able to fly to the target area. The FAC then takes over to make sure that the *eyes* of the pilot are guided onto the correct target and that the pilot is aware of the position of friendly units in the target area such that they are not endangered.

To accomplish his task, the FAC chooses an observation position (OP) in the terrain from where the target area can be well observed, while at the same time an unobstructed view is provided in the direction where the plane is expected to show up. From the OP, the FAC continuously observes the enemy units, most specifically the designated target, the friendly units and (when in sight) the plane.

The FAC provides guidance cues to the CAS pilot via a UHF radio connection. This radio communication has to conform to a NATO standard procedure for FAC operation.

In situations where it is difficult to find clear marking points in the terrain, the FAC has several ways to create artificial reference points: special light reflectors or lamps, smoke grenades, and flares can be used for this purpose. Most CAS planes are also equipped to detect laser target designator signals. The FAC then uses a laser target designator to point out the target by putting the laser spot upon it.

CURRENT TRAINING PRACTICE

A typical initial FAC training course currently takes three to four weeks. The first part of the course, about a week, covers theory: air operations in general, CAS operations, NATO standard FAC procedures, map handling, radio operation, radio procedures, etc. After this, the practical issues are divided into two parts: low threat and high threat operations.

Low threat FAC operation is commonly considered to be relatively easy. A FAC who is qualified for high threat operations, is also assumed to be qualified for low threat. Low threat operation is only trained by using aerial photographs as a visualisation tool. The 'pilot' (usually an instructor) is given an aerial photograph of the target area as it would be seen from the plane when circling above the area. The FAC trainee has prepared the scenario with a map and possibly with observations in the real terrain. The goal of the exercise is then for the trainee to 'talk' the eyes of the pilot onto the correct position on the aerial photograph.

Most training effort is put into high threat operations. Training for high threat FAC operations is currently facilitated in three ways in addition to theoretical instruction:

- Review of video and voice recordings that are taken from a cockpit during FAC operations (so-called HUD tapes);
- Classroom simulation by using a scale model of a target area and a toy plane;
- Live training runs.

HUD tapes and scale model simulation are only used in the first week of the course. The remainder of the course is filled with live training runs to exercise high threat training as much as possible. Low threat scenarios are usually not trained with live training sorties.

Training Bottlenecks

Analysis of the current FAC training practice shows a number of bottlenecks that reduce both the effectiveness and the efficiency of current training:

- Moving from classroom training to live training for high threat operation proves to be too big a step, as witnessed by the bad results of the first series of live training runs;
- Limited availability of flying hours for live training sorties often severely impedes the training course (due to, for example, cost restrictions, capacity restrictions, flying restrictions, weather restrictions and bird activity restrictions.)

- Live training is the only effective training tool for high threat FAC operation, but it is a very expensive tool to use to this end.

These bottlenecks have been taken as the starting point for the hypothesis that a new simulation tool will solve them, and improve both the effectiveness and efficiency of FAC training.

Problem Approach

To test the hypothesis that an HMD-based training simulator would solve the above mentioned bottlenecks, the following approach has been followed:

- A *task analysis* of FAC operation has been performed;
- A *training objective analysis* for initial FAC training has been performed;
- The training objectives have been *mapped on training tools*, to find out which training objectives should be reached with the simulator;
- A set of initial *user and system requirements* has been defined for the FAC simulator;
- A *prototype* simulator has been built;
- an *evaluation* of the prototype simulator has been performed to test the hypothesis and assess the feasibility of the FAC simulator.

Simulator Solution

The FAC task analysis and training objective analysis results indicate that FAC training can be improved by providing a simulator tool that aims to contribute to the following training objectives:

- Planning of a FAC operation:
  - Creating a mission brief;
  - Selection of a suitable OP;
- Pilot guidance:
  - Communication procedure with the pilot;
  - Recognising and adjusting the plane's flight path;
  - Observation of the environment;
- Battle damage assessment.

These training objectives are currently covered by either classroom instruction that lacks realism or by live training that is not cost-effective.

The essence of the FAC simulator is that it shall provide a training tool that bridges the gap between the standard classroom instruction and the live training. The simulator shall enable the FAC trainees to experience and exercise FAC procedures in a realistic way (i.e., with realistic time pressure and realistic visual perception tasks) before they are exposed to real planes.

It is claimed that an HMD-based virtual environment system embedded in a distributed interactive simulation network (see Figure 1) will provide this bridge between theory and practice.

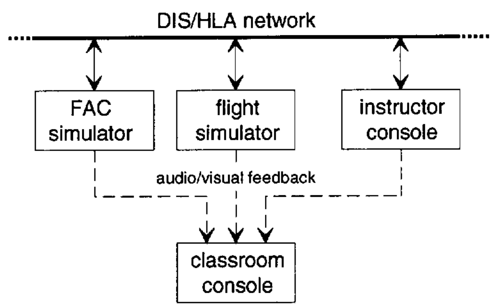

Figure 1. The conceptual structure of the FAC training simulator system.

The need for an HMD (see Figure 2) is motivated by the requirement that the FAC must be able to fully observe the environment around him, since CAS plane and target are usually in opposite direction. An HMD is advantageous over other projection displays in the fact that it provides visual feedback covering the entire 360° azimuth and 180° elevation field of regard in a very small and affordable device. Because of this, the HMD is very suitable for tasks that rely on spatial perception of an environment, as is the case with FAC operation.

Evaluation Method

The simulator solution presented in the previous section was prototyped within TNO's Electronic Battlespace Facility [2]. This prototype enabled us to evaluate whether the proposed HMD based training simulator solution is a valid and acceptable solution. A concise description of the prototype can be found in [3]. For the course of this paper, it is relevant to note that:

- The HMD used for the prototype is an n-Vision HiRes stereoscopic display device that displays 1280x1024 pixels in each eye. The optics of the HMD project the images onto a field of view of 63° horizontally by 34° vertically per eye, with a 50% overlap between the two images. This yields a resolution of 1.6 arcmin per pixel.
- The HMD is tracked by an InterSense IS-300 PRO tracking device that continuously reports the viewing angles of the FAC trainee. The IS-300 uses inertial technology to determine the FAC's viewing direction.
- The stereo images for the HMD are provided by a Silicon Graphics Onyx^2 with a single Infinite Reality pipe. Average frame rate was 30 to 60 Hz.
- Figure 3 depicts a typical database scene as seen by the FAC.
- While performing simulator exercises, the classroom console provides a simultaneous view of the scene as seen by the FAC and the pilot as well as a map view of the target area. These images are presented on large retro projection screens.

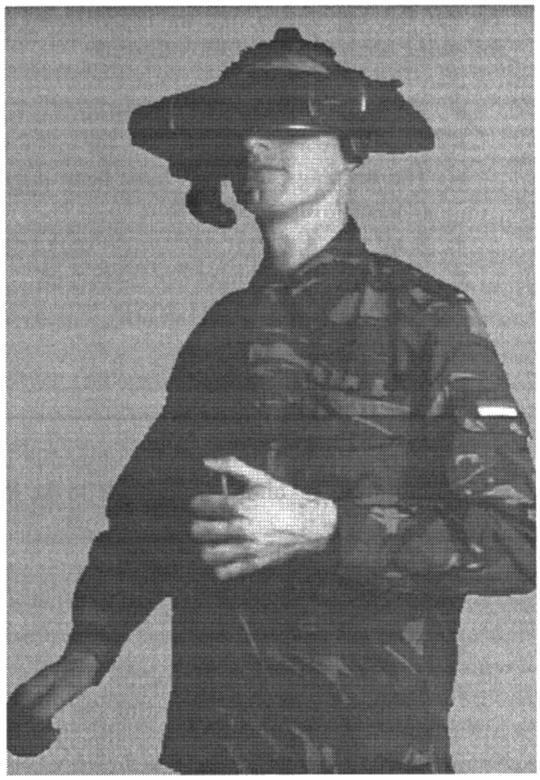

Figure 2. The FAC simulator uses a Head Mounted Display to immerse the FAC in the working environment.

Prototype evaluation has been done in five sessions. In the first two sessions, only FAC instructors were involved, whose primary aim it was to assess whether it is possible to simulate FAC operations with the simulator, and secondly whether the system is as suitable as an instruction tool.

After the positive outcome of the first two evaluation sessions, the prototype was to be further evaluated in three regular FAC courses as given by NIAGOS. The objective of these sessions was to determine how inexperienced trainees would cope with the system and what the learning transfer would be. In the first week of the course, after trainees had caught up with theory, simulation training was performed during a single day. Practical constraints limited the use of the simulator to only a single day per course - ideally the simulator should be used during the whole course.

The evaluation is limited in the fact that it has been mainly qualitative in nature. A lot of issues require further evaluation and quantification. However, the evaluation that has been performed enables us to answer the main question of this feasibility study, namely whether the HMD based FAC training simulator can be a tool to resolve current FAC training bottlenecks.

Figure 3. A typical view on the virtual target area as seen by the FAC through the HMD

Evaluation Results

The main outcome of the evaluation sessions is that the FAC simulator proves to be a valid simulation of FAC operation and that it can be used effectively to improve FAC training.

Improved Training Effectiveness

The first observation is that the use of the FAC simulator enhances training effectiveness. Taking into account that only a single day of simulator training was integrated in the course, it was already observed that the initial live training runs after simulator training were more successful than in courses without simulator training.

The main reason for the fact that the simulator enhances training effectiveness, is that the simulator is a more suitable tool to train novice FACs than exercising on live training runs. When using only live sorties as a training tool, the trainees will need many runs to get to a certain minimum capability level. Many of these runs will fail. Using the FAC simulator for this stage of training demonstrates it to be a more effective way to push the trainees to a desired initial capability level. The reason behind this is that simulator training is much more controllable than live training - the level of the exercises can be matched with the capabilities of the individual FAC.

Improved Training Feedback

The use of a classroom console has proven to be a very valuable instruction tool. The correlation of the FAC's view with the flight simulator view in particular provides trainees good insight into how a pilot perceives the terrain, thus learning which cues are best used for visual guidance.

The use of the scenario freeze and scenario playback feature also demonstrated the value of simulation over live training. During live training, there is little opportunity to evaluate runs. Only after the planes have returned to base, the HUD tapes can be reviewed and the pilots can give their comments on the runs. Simulation, on the other hand, allows direct feedback on the trainee's behaviour.

The improved feedback also facilitates the instructor in the evaluation of a trainee's performance. It is observed that this evaluation is currently done in a very subjective and informal way. The evaluation could be pushed to a more objective level by introducing automated support for it. The available DIS/HLA network data and communications recording could be a source of information to extract objective scoring data.

Improved Training Flexibility

Having the control to fly sorties in the simulated world at any desired time, any desired place, and in any desired pattern has proven to be a relief for FAC instructors. Current FAC courses are continuously impeded by uncontrollable variables like weather, birds, mechanical problems with planes, etc., which are fully controlled in the synthetic training environment.

Human Performance Issues

Several important human factors issues have been observed during the evaluation sessions of the prototype:

- All trainees accept the HMD based simulator as a useful and pleasant tool - no simulator sickness or discomfort was reported;
- To obtain visual aircraft detection ranges that are realistic (5 to 8 kilometres), the aircraft model is scaled up 8 times (and gradually scaled down to a 1:1 size as it approaches the FAC);
- Trainees are indeed able to give visual guidance control to the pilot by perceiving the position and orientation of the plane;
- Trainees have some difficulties in getting the right orientation within the terrain (this problem has been reduced by displaying a heading reading at the bottom of the screen).

Technical Issues

From a technical point of view, the experiments with the FAC simulator prototype have taught us the following lessons:

- The InterSense tracking system is superior over often used electromagnetic tracking systems, considering both accuracy and speed - a comparison between the two has shown considerably improved perception capabilities for target detection, due to absence of lag and jitter;
- A large amount of system development effort will have to go into database development - a diversity of high quality databases is a prerequisite for a fully operational training simulator.
- The distributed architecture of the FAC simulator, relying on the standard DIS/HLA concepts, provides ample opportunities for the development of a fully functional and extendible simulator.

Simulator Opportunities

The current study has only touched upon FAC simulation to a limited extent: the use of simulation for initial training of high threat FAC operations. However, simulation brings a lot more opportunities. The full list of applications includes:

- Personnel selection;
- Initial training;
- Currency training;
- Currency testing;
- Mission rehearsal.

FACs who already have a combat ready status, will need training to keep up their currency. Currency training with the simulator will be a good approach for this purpose. Within NATO, combat ready FAC's have to perform six successful runs every half year. A combat ready FAC has once been reported to need eighteen runs to perform six successful ones. It would have been much more cost effective if these twelve unsuccessful runs would have been performed in a simulator.

For currency training, the FAC simulator can be connected to a real flight simulator, possibly situated at a remote air base, via the DIS/HLA network. Thus, both FAC and CAS pilot can be trained to keep up currency.

Once simulation is an accepted tool in FAC currency training and has demonstrated to decrease the number of currency test runs that is required to fulfil the NATO currency requirement, simulation may well become a mandatory part of currency tests.

As the application of the simulator is extended to currency training and even currency tests, the requirements for the simulator are also extended. More complex scenarios need to be simulated, including threat handling, multiple CAS planes and more difficult conditions like night CAS operations.

For mission rehearsal application, not only the complexity of the scenario is increased, but also the need for a geospecific database of the mission area is put forward, as is the simulation of dynamic threats of various kinds (enemy aircraft, ground forces, radar, etc.)

All these opportunities indicate that FAC simulation provides ample means to increase the capabilities of FACs, while in the end a strong reduction of cost can be effected due to a reduced number of live training runs that is required. At the same time, the live training runs that are still performed - and necessary - are used more effectively.

FURTHER WORK

The FAC simulator has been received with great enthusiasm within the FAC community. The fact that both research and development on this subject have only been partly touched upon, imply that a lot of work remains to be done. Here are some of the topics:

- Conduct a more quantitative study of the impact of the simulator on training effectiveness and efficiency;
- Find ways to solve the terrain orientation problem by displaying auxiliary information in the HMD - without introducing negative training transfer;
- Introduce objective trainee evaluation concepts and automated support for this to push the current subjective scoring methods to a more objective level;
- Develop a fully operational FAC simulator.
- Allow for more complex scenarios, such as threat handling, and night CAS procedures;
- Extend the concept of the simulator to airborne FAC, heli-FAC, and forward artillery observers (FO).

CONCLUSION

The main conclusion of our FAC study has been that introduction of an HMD based simulator for FAC training is feasible and will greatly enhance training effectiveness and efficiency. Evaluation of the prototype system within a series of three FAC courses has shown that the simulator is accepted by the trainees as a useful tool to learn with and by the instructors as a useful tool to teach with.

By filling the gap between classroom training and live training, the FAC simulator solves all bottlenecks inherent to current training practice. The advantages and the enthusiasm of the users that have been observed during the evaluation of the prototype makes TNO believe that FAC simulation will be among the first applications of HMD based simulation systems that will come to an operational status.

STINGER TEAM TRAINER

Stinger is a man-portable, shoulder-fired, ground-to-air missile weapon system. It is mainly used to provide air defence against high-speed, low-level, ground-attack aircraft and helicopter. The system is operational with the Royal Netherlands armed forces (all three of Air Force, Army and Navy) and the armed forces of many other nations.

Back in 1992, the TNO Physics and Electronics Laboratory developed a simple concept demonstrator that illustrates how HMD-based virtual environment technology can be applied to Stinger training (see Figure 4). It took until 1995 for the Royal Netherlands Air Force to catch up with this concept and investigate whether a VE based simulator could benefit Stinger training. This resulted in a paperwork study by TNO that revealed the opportunities of a VE Stinger

trainer, but at the same time raised a number of unresolved questions with respect to the optimum design of such a VE Stinger trainer [4].

To answer the questions that have been raised by the paper work study in 1995, a new project has been planned to go on starting in 1998. The problem statement and planned approach of this project is described in the following sections.

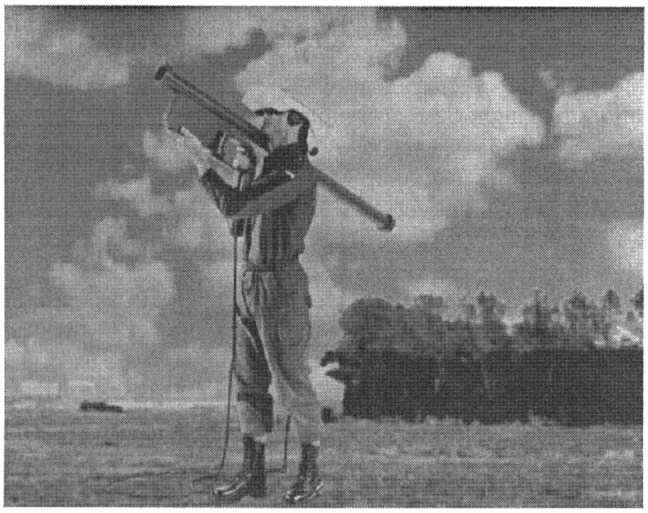

Figure 4. - The HMD based Stinger Trainer concept demonstrator as built by TNO in 1992 (background image is image as seen in the HMD)

Current Training Practice

The Dutch armed forces currently have the following training devices available for Stinger training:

- A dome-based trainer (see Figure 5) that provides a slide-projected terrain and up to two moving targets on a 20 metres diameter dome;
- A video-equiped training weapon system that is used in conjuction with live flying exercises;
- The Stinger Troop Proficiency Trainer (STPT), a training weapon system with a small visor display that shows a virtual terrain with virtual targets.

Novice Stinger personnel receive their initial training in the Stinger dome trainer. Combat readiness is then ensured in exercises with the video-based trainer and in live training at a shooting range. The STPT is supposed to be used for currency training (in practice, the STPT is not used at all).

Training Bottlenecks

The Royal Netherlands Air Force have indicated a requirement for better currency training tools. The new currency training tool shall:

- Provide a broad range of training scenarios with complexity varying between novice level and extended air defence exercise levels;
- Enable simulation of all Stinger part tasks;
- Enable full team training;
- Be mobile.

None of the three training devices mentioned above fulfils these requirements. Subject of study is whether HMD-based virtual environment technology can do this job. An intrinsic issue here is that an HMD based Stinger trainer assures mobility while still providing a full 360 degrees field of view.

Problem Approach

Based upon earlier work for Stinger training, the question whether a VE Stinger trainer is a feasible and valid solution to the Stinger training requirements has been reduced to first get answers on the following questions:

a. To what specifications shall a mobile Stinger team training system adhere with respect to the following critical issues:

   - The type of display system;
   - The tracking system performance;
   - The end-to-end system latency.

b. What is the expected learning transfer for a VE technology based mobile Stinger team training system?

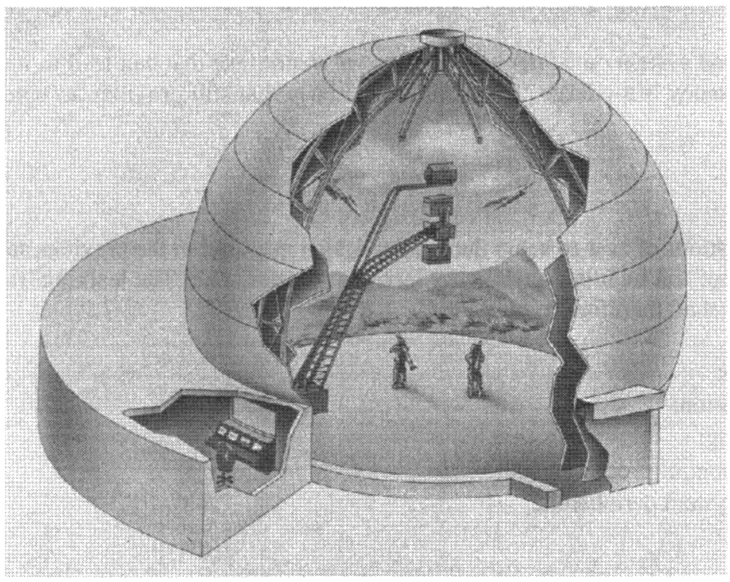

Figure 5. The Dutch armed forces currently use a dome-based training device for Stinger training

Display System

The most crucial and unclear aspect about the Stinger team training system is the way to setup the display system. We think of the following options to configure the display system:

- Stereo immersive HMD;
- Stereo see-through HMD;
- Stereo see-through HMD combined with a visor display to obtain high precision target display;
- Mono see-through HMD on the left eye combined with a visor display used by the right eye;
- Projection screen;
- Projection screen combined with a visor display to obtain high precision target display.

The main issue to deal with here is the physical interaction between the head and the weapon system. In normal operation, the gunner will put his head against the visor. An HMD is a very elegant device to display a large surrounding environment with a yet small device, but it makes the physical contact between head and weapon system impossible.

The latter three options listed above do enable the gunner to lay the head against the weapon. Most notably the configuration with a mono see-through HMD on the left eye and the visor display on the right eye is an interesting option to investigate.

Tracking System

A tracking system is required to measure the position and orientation of both the HMD and the weapon. Given the small measures of the visor, this is a very accurate task. The tracking system shall therefore be:

- Accurate;
- Noise free;
- Fast.

It shall be determined what requirements are to be laid upon the performance of the tracking system with respect to these aspects. In addition to this, the characteristics of the tracking system can influence the operational restrictions of the training device. Some tracking systems put restrictions on the operating environment, or are very difficult to set up - this can conflict with the mobility requirement.

System Latency

Aiming a Stinger weapon system on a target is a perceptual motor task that can lead to unstable control in a simulator if end-to-end system latency is too large. The maximum latency that still provides acceptable simulation validity shall be determined.

Learning Transfer

The answers to the questions of how to setup the system design as posed in the previous sections are only of value if the VE simulator concept will be bring satisfactory learning transfer at all. The learning transfer with respect to the following Stinger tasks shall therefore be measured:

- Target detection;
- Target identification;
- Aiming and firing;
- Command and control processes;
- Using weapon system peripherals;
- Team operation.

Evaluation Method

The issues raised in the previous section will be dealt with by building an experimental Stinger team training system. The experimental system shall provide full functionality to simulate all relevant Stinger tasks and at the same time be flexible to enable the setup of different configurations with respect to the display system, the tracking performance and the end-to-end system latency.

The experimental system will then be used for evaluations in three stages:

- Component level evaluation;
- Part task evaluation;
- Integral evaluation.

Component Level Evaluation

The component level evaluation addresses the quality of the individual components used in the experimental system. The following aspects are investigated:

- The quality of the display systems;
- The quality of the tracking system;
- The ability to position the head with respect to the weapon system;
- The end-to-end system latency.

The results of this stage are required to interpret the results and identify involved causes in the remainder of the evaluations.

Part Task Evaluation

The part task evaluation aims at measuring human performance with respect to Stinger part tasks when using a specific configuration of the experimental Stinger trainer. Part task times and accuracies will be measured.

Integral Evaluation

The integral evaluation aims at measuring the learning transfer by determining human performance when performing a Stinger attack as a complete procedure. Hit-rates and procedure timing will be measured for a group of subjects on a typical series of Stinger training exercises. Part of the group will be subject to a number of different configurations of the experimental Stinger trainer. The subjects' exit level will be determined by going through a live training with video recording.

CONCLUSION

A HMD-based virtual environment system may provide a solution to the Stinger training problem, as the HMD provides a display system that provides a large field of regard, yet in a small, hence portable, device. The success of this system depends on a number of critical factors of which the display system and the corresponding physical interaction between the head and the weapon system is primary, then tracking performance and end-to-end system latency. The planned project will eliminate uncertainty on these factors.

Conclusions

As has been said in the introduction: The use of HMD technology in virtual environments for training simulation has always been recognised to be of great potential. So many have been proclaiming the infinite spectrum of applications that virtual environment technology will have in our daily lives. And so many are still waiting for real applications of this technology to appear.

The Forward Air Controller training and Stinger team training applications in the military field have made us confident that real applications of HMD-based virtual environment systems do exist. The Forward Air Controller training study has proven that this type of system is accepted by the military users as a useful training tool.

ABOUT THE AUTHOR

Frido Kuijper is a research scientist in the Command & Control and Simulation Division at TNO-FEL. He has been involved in VE technology and its military applications ever since the R&D program in this field started in the early nineties. He is leader of the project on the application of VE technology for FAC training and several other VE related projects for the Dutch armed forces. He holds an M.Sc. in Computer Science from Delft University of Technology (NL) and specialises in visual simulation, display systems and tracking systems.

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14. Abstract

The purpose of the workshop was to examine military requirements for Virtual Reality technology, consider human factors issues in the use of Virtual Reality and review recent research in development of Virtual Reality applications to meet military needs.

The workshop was organized into three day long sessions. The first day focused on military applications for Virtual Reality systems and identified particular requirements for Human Factors research to meet the requirements. The second day examined Human Factors issues in the use of Virtual Reality technology. Presentations discussed sensory interfaces, measures of effectiveness, importance of the sensation of presence, and cybersickness. The third day reviewed assessment methods and applications research. Speakers reviewed existing or completed Virtual Reality projects designed to meet military needs. The papers discussed how the projects overcame human factors problems and how their effectiveness was evaluated.

Virtual Reality technology is of great interest to the military. Requirements for its use encompass a wide range of applications including concept development of systems for dismounted combatants, mission rehearsal for special operations, training ship handling skills, telerobotics, and practicing military medical procedures. Virtual Reality's success in meeting these needs will be determined by the ability of its human-computer interfaces to provide the means necessary to deliver stimuli and allow appropriate responses from those using it. These human factors issues were the focus of the workshop. The workshop pointed to areas that require further research and development in order for Virtual Reality to meet its potential for the military.

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